EMBRAER Contribution to HiLiftPW-3

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EMBRAER

AIAA SciTech Forum and Exposition 2018
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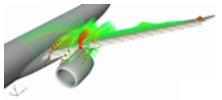
EMBRAER

Outline



Description of code used

Summary of cases

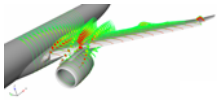
Overview of grids used

Overview of results

- CRM
- JSM

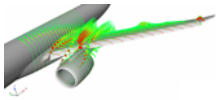
Concluding remarks

Summary of code and numerics used



- All simulations performed using CFD++ code:
  - RANS numerical solver
  - Finite-volume method, upwind fluxes and reconstruction algorithms for higher spatial order of accuracy.
  - Time march performed with a point-implicit method and multigrid for convergence acceleration
  - Many turbulence models: used SA with Curvature Correction (CC) and Quadratic Constitutive Relation (QCR)
  - All cases run with restart from previous AOA
  - Developer website
    - http://www.metacomptech.com/index.php/features/icfd

Summary of cases completed: CRM

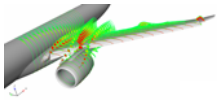


Case	SOLVER	Turb. Model	Workshop		Extra
			Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Full CL x Alpha
			Grids		
1a (full gap)	CFD++	SA-CC-QCR	B2, B3, M5	B2, B3, M5	B2, B3, M5
1b (full gap w adaption)					
1c (partial seal)	CFD++	SA-CC-QCR	B2, B3	B2, B3	B2, B3
1d (partial seal w adaption)					

Mean aerodynamic chord (MAC) = 275.8 in (7.0053 m)
Wing semi-span = 1156.75 in (29.38 m)
Reference area of the semi-span model = Sref/2 = 297,360.0 in2 (191.8448m2)
Moment reference center (MRC): x=1325.90 in, y=468.75 in, z=177.95 in
x=33.6779 m, y=11.906 m, z=4.5199 m

Conditions: M=0.20, Rey=3.26E+06
AOAs: 0, 4, 8, 10, 12, 14, 15, 16, 18, 19, 20, 21 and 22°

Summary of cases completed: JSM

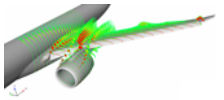


Case	SOLVER	Turb. Model	Workshop		Extra	
			Polar, Fully turb	Polar, w/ transition prediction	No slat brackets	Standoff and viscous tunnel wall
			Grids			
2a (no nacelle)	CFD++	SA-CC-QCR	C2, E		E_mod	E_mod2
2b (no nacelle w adaption)						
2c (with nacelle)	CFD++	SA-CC-QCR	C2, E		E_mod	E_mod2
2d (with nacelle w adaption)						

Mean aerodynamic chord (MAC) = 529.2 mm
Wing semi-span = 2300.0 mm
Reference area of the semi-span model = Sref/2 = 1,123,300.0 mm2
Moment reference center (MRC): x=2375.7 mm, y=0.0 mm, z=0.0 mm

Conditions: M=0.17, Rey=1.93E+06
AOAs: 0, 4.36, 8, 10.47, 13, 14.54, 17, 18.58, 19.59, 20.59 and 21.57°

Summary of cases completed: 2D Turbulence model verification study

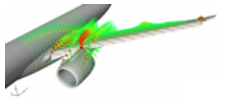


Case	SOLVER	Turb. Model	Workshop	Extra
			2D Verification study	Other
Case 3	CFD++	SA-CC-QCR	Comittee 1, 2, 3, 4, 5	
	CFD++	SA	Comittee 1, 2, 3, 4, 5	

Mean aerodynamic chord (MAC) = 1.0 m

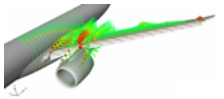
Conditions: M=0.09, Rey=1.2E+06

Brief overview of grid system(s)

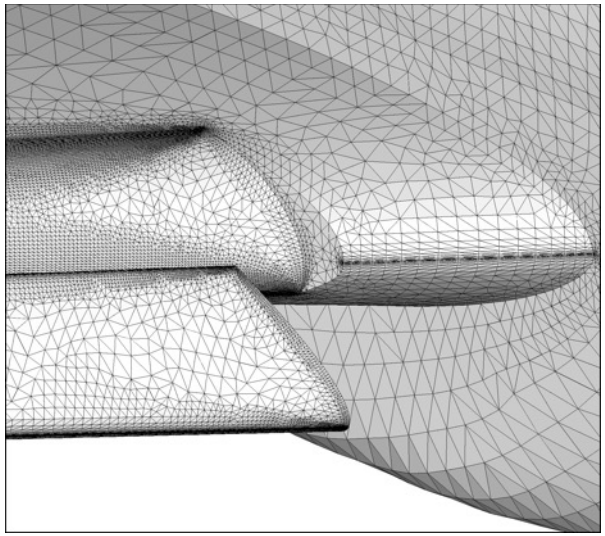


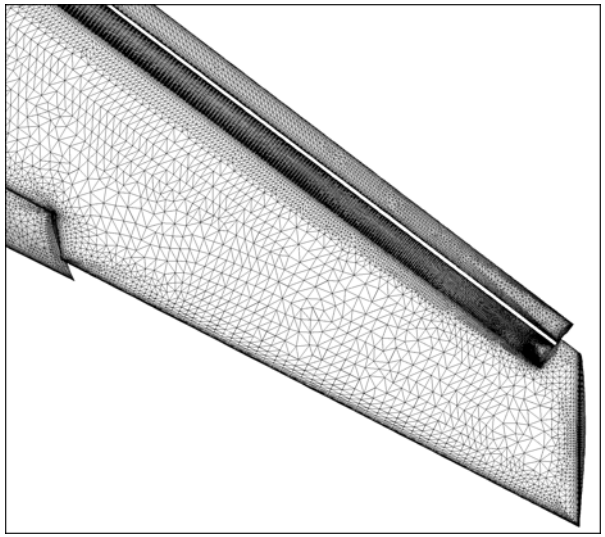
Geometry	Case(s)	Grid System	Source	Refinement	Problems/Issues/Observations
CRM (Full Gap)	1A	B2	Committee	Coarse, Medium, Fine, Extrafine	Extra-fine grid is very large
	1A	B3	Committee	Coarse, Medium, Fine	
	1A	M5	EMBRAER	Coarse, Medium, Fine	More uniform grid More refined at LE Fine grid is very large
CRM (Partial seal)	1C	B2	Committee	Medium	
	1C	B3	Committee	Medium	
JSM	2A,2C	C2	Committee	Medium	
	2A,2C	E	Committee	Medium	
	2A, 2C	E_mod (*)	EMBRAER	Medium	Similar to mesh_family E, but without slat brackets
	2A	E_mod2 (*)	EMBRAER	Medium	Similar to mesh_family E, but with standoff and viscous tunnel wall

CRM grid comparison: B2, B3, M5 (coarse)

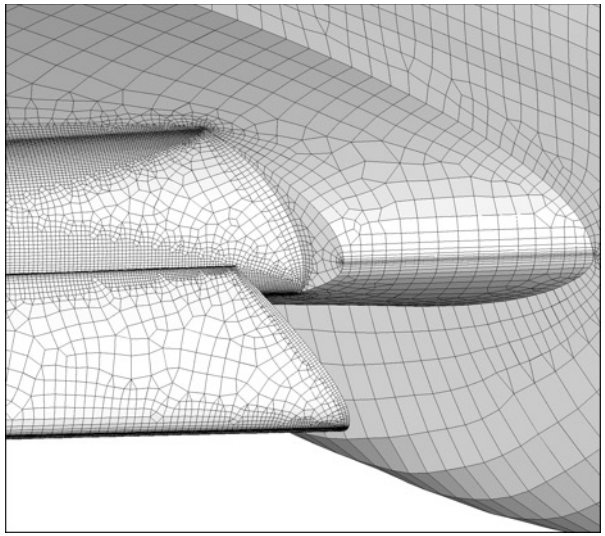


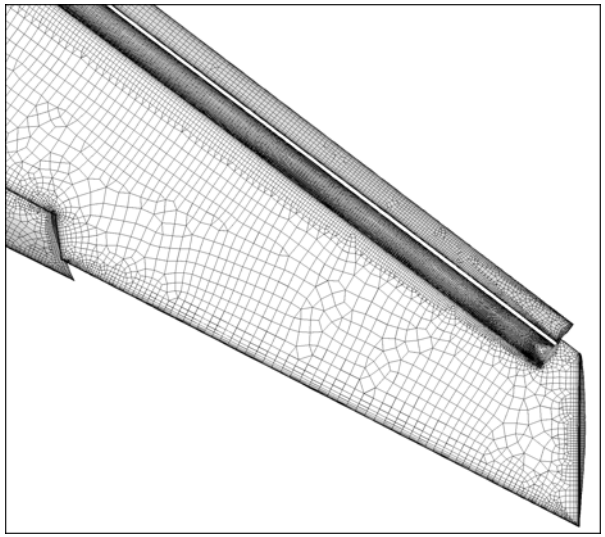
B2 (22 millions)



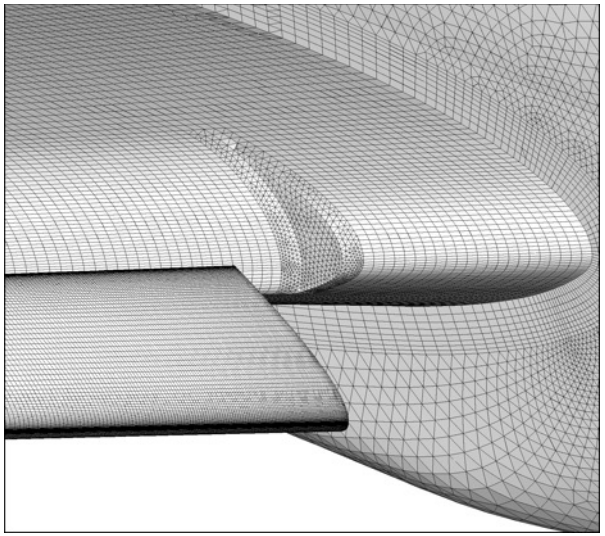


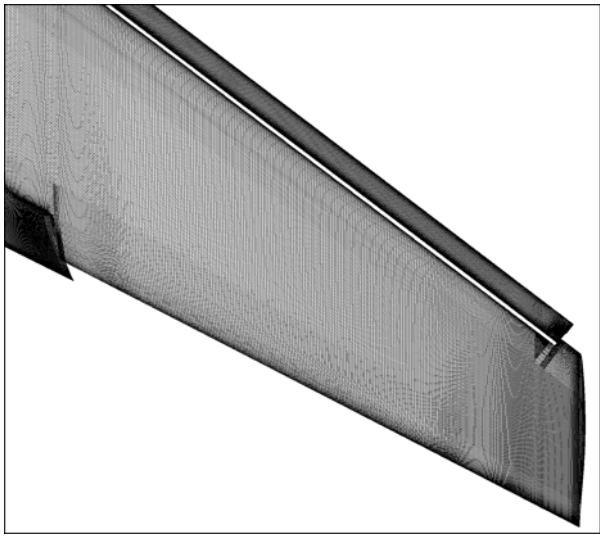
B3 (18 millions)



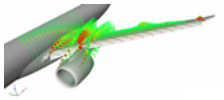


M5 (36 millions)

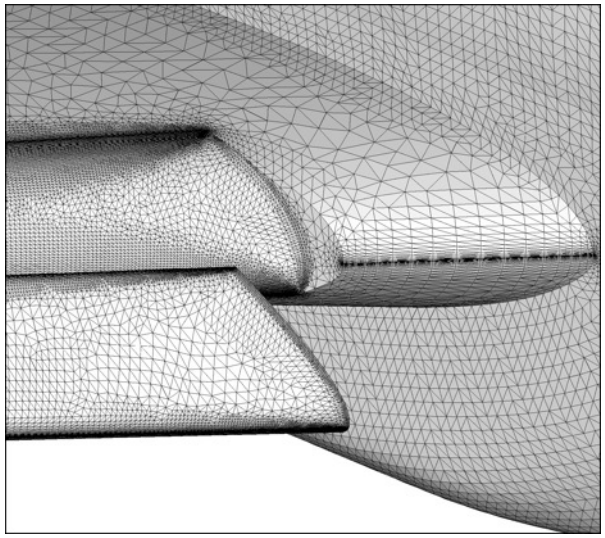


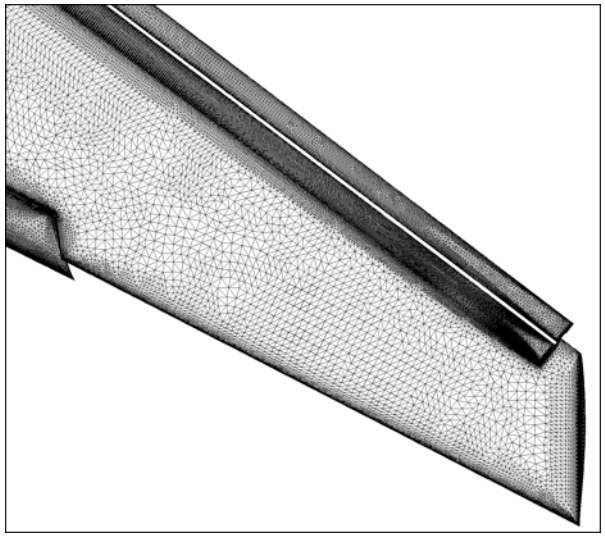


CRM grid comparison: B2, B3, M5 (medium)

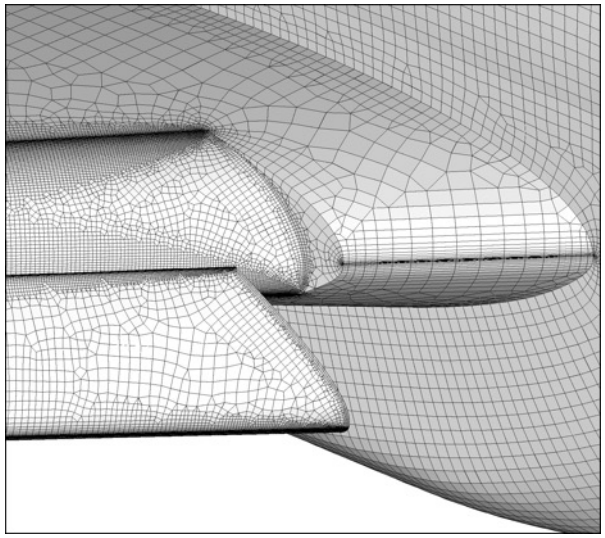


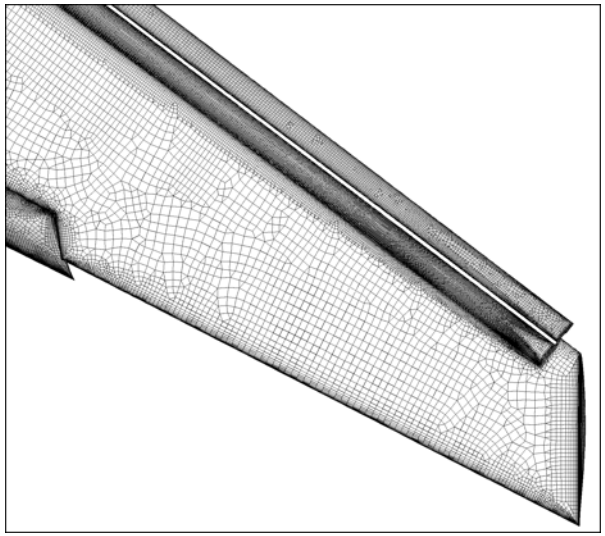
B2 (64 millions)



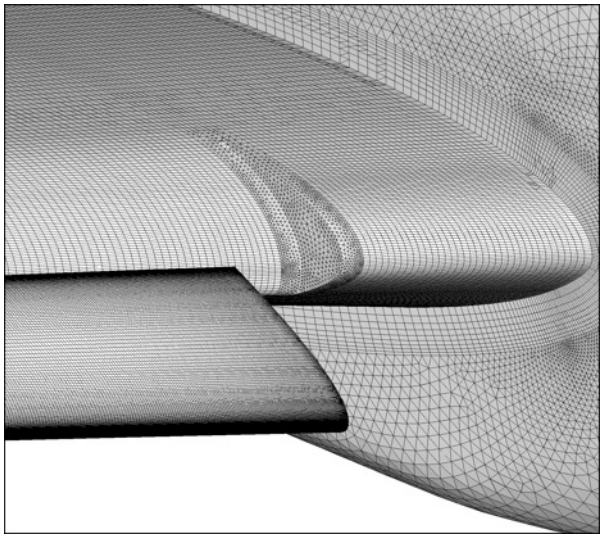


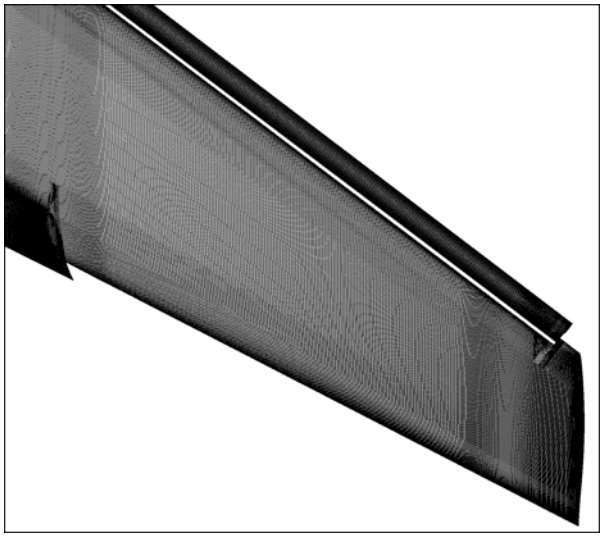
B3 (47 millions)



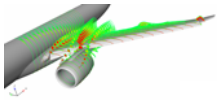


M5 (111 millions)

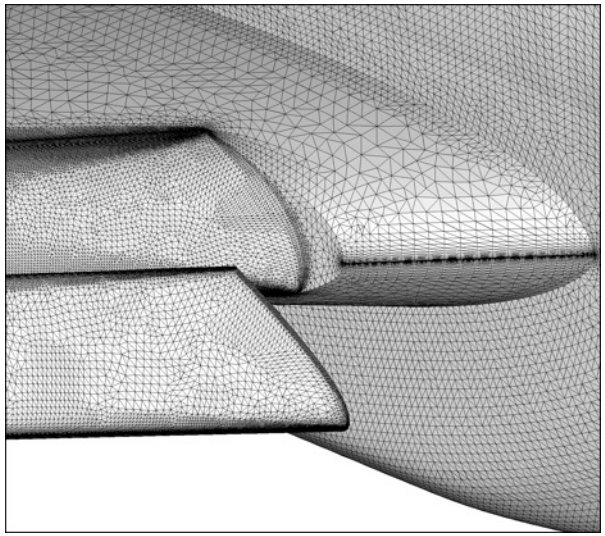


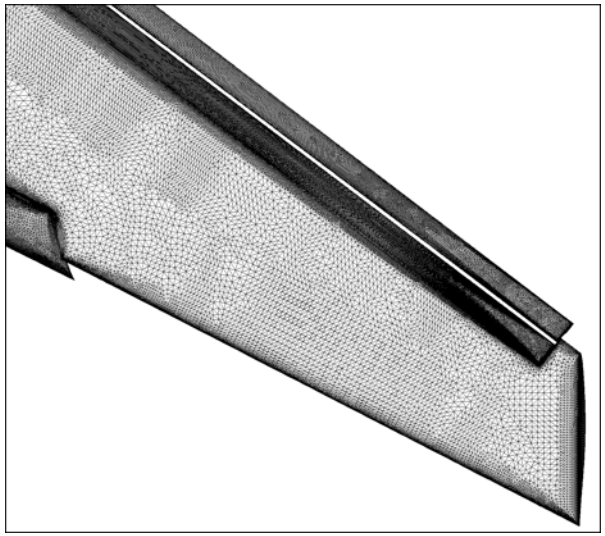


CRM grid comparison: B2, B3, M5 (fine)

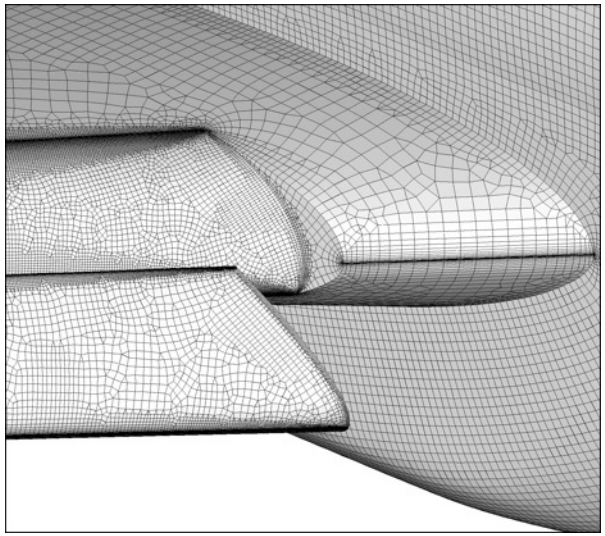


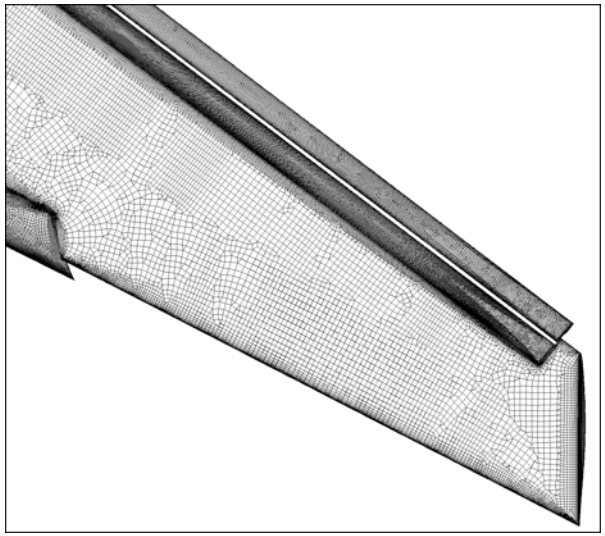
B2 (169 millions)



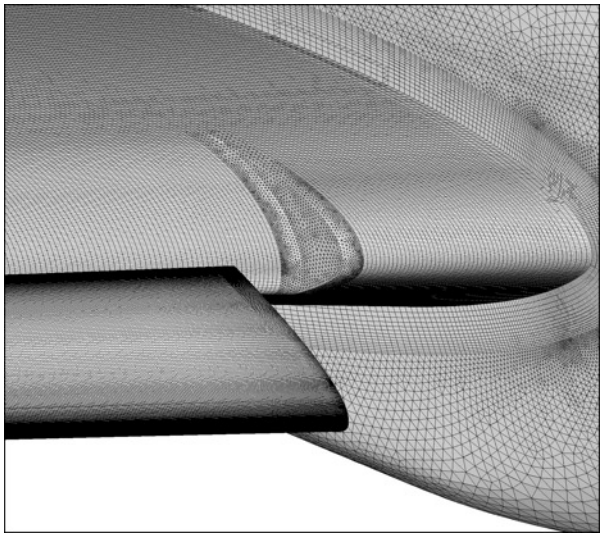


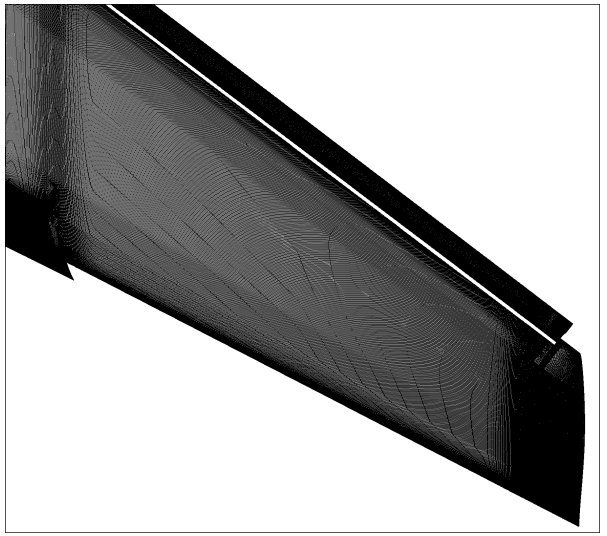
B3 (118 millions)



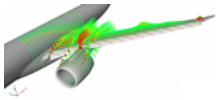


M5 (345 millions)

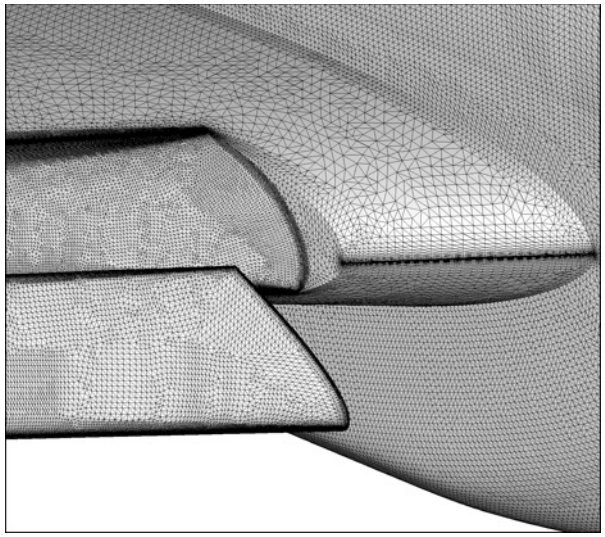


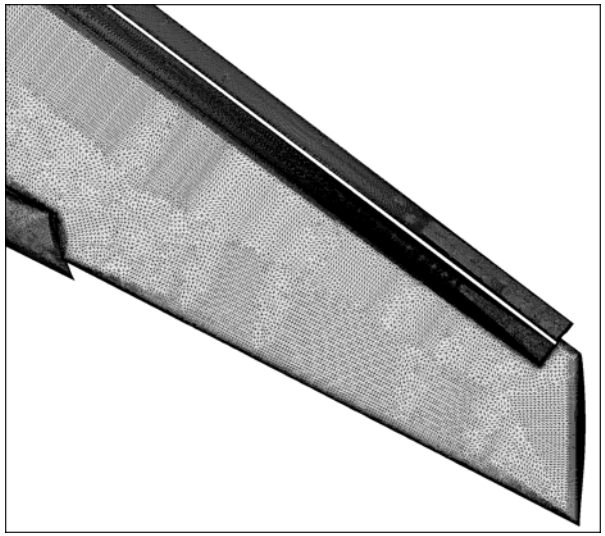


CRM grid comparison: extrafine B2, fine M5

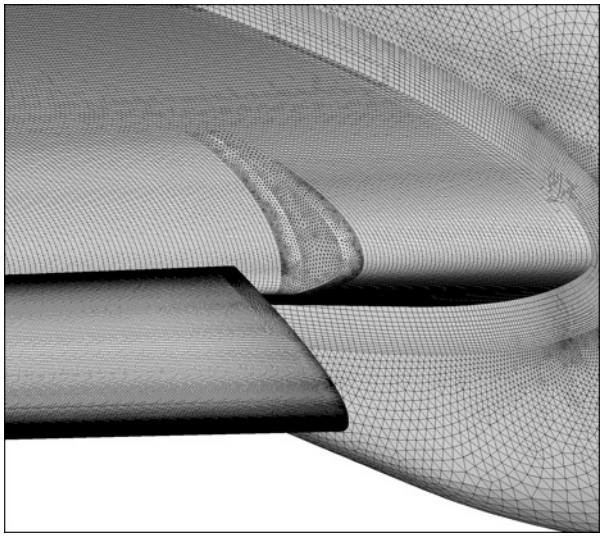


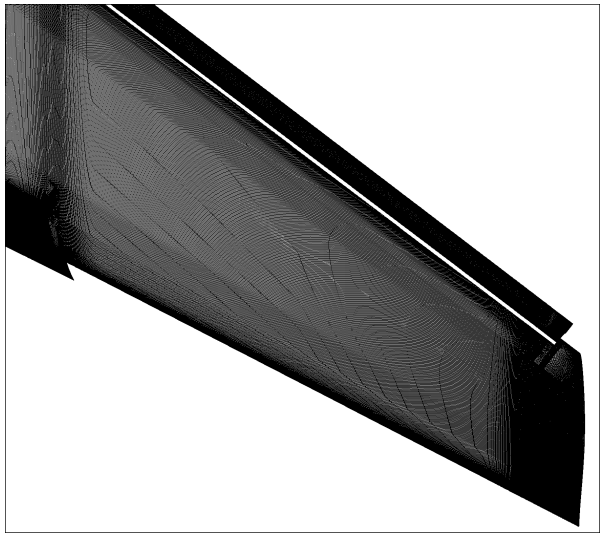
B2 (541 millions)



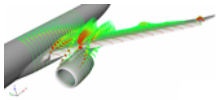


M5 (345 millions)

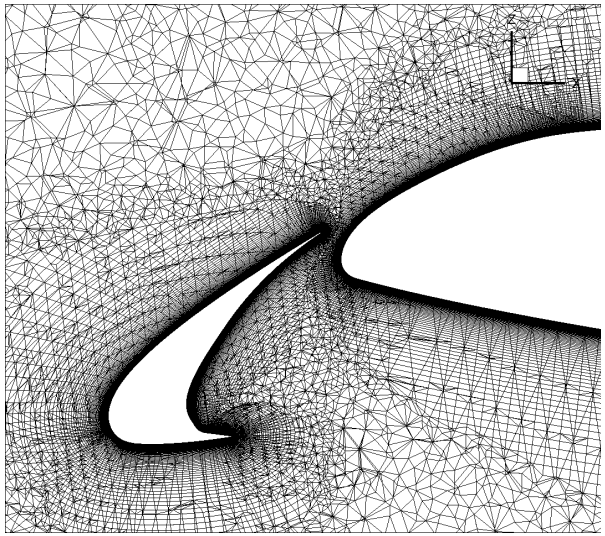


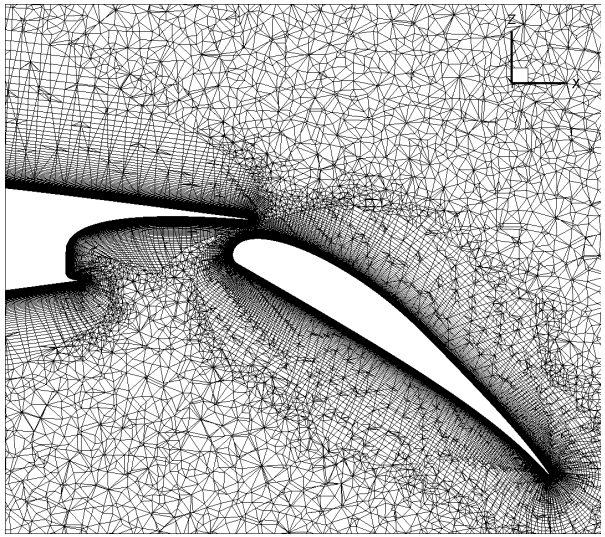


CRM grid comparison: extrafine B2, fine M5

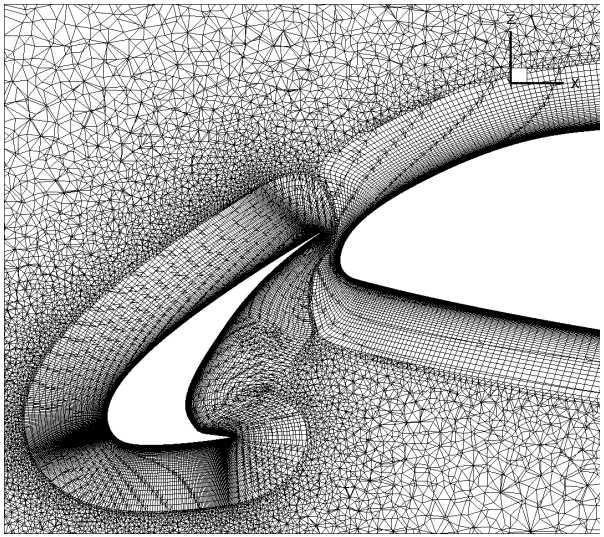


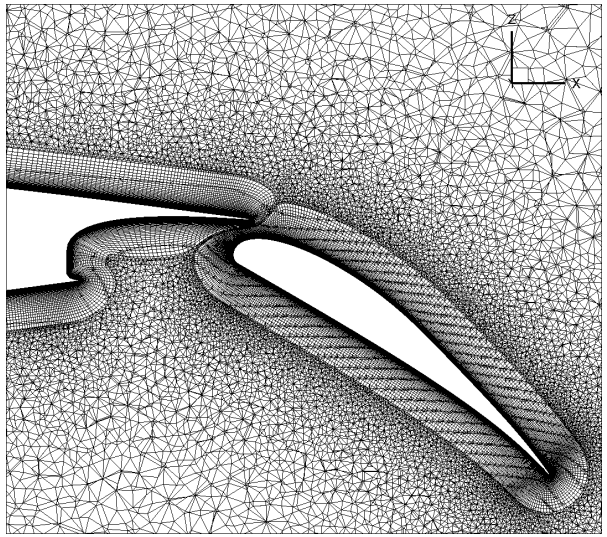
B2



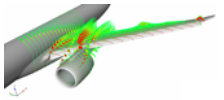


M5

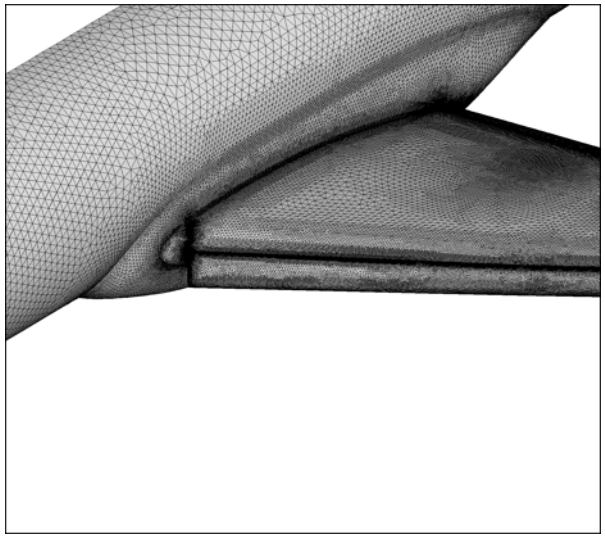


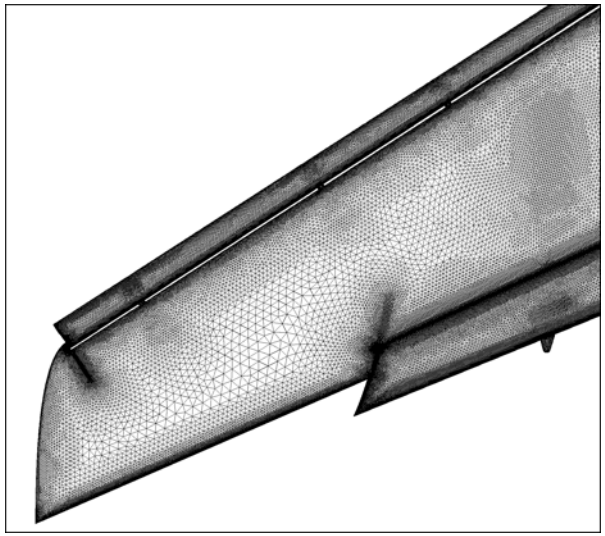


JSM grid comparison (PyNa Off): C2, E

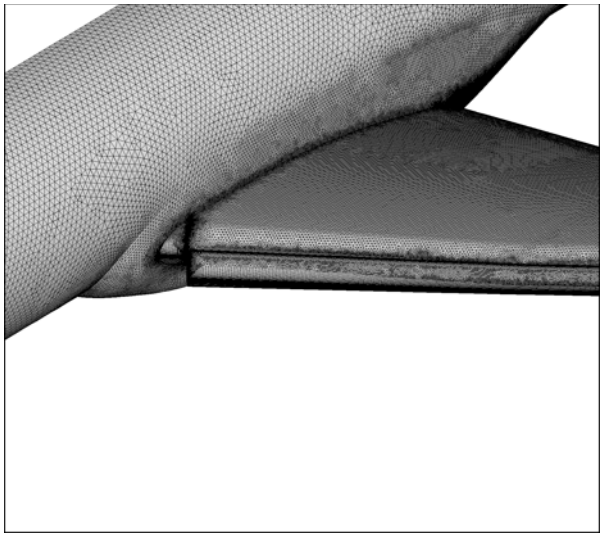


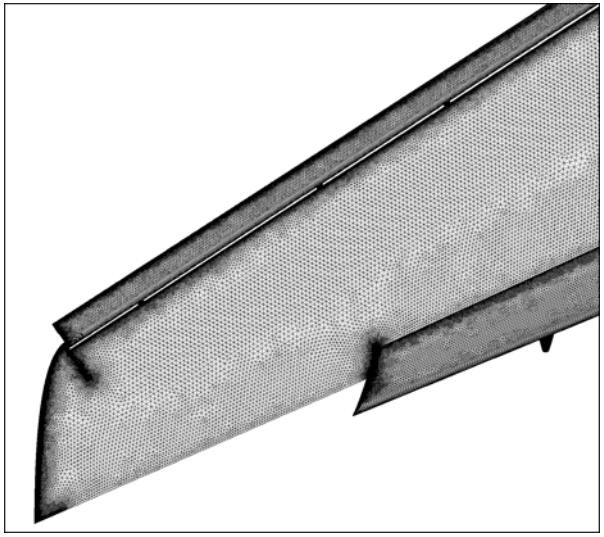
C2



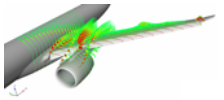


E

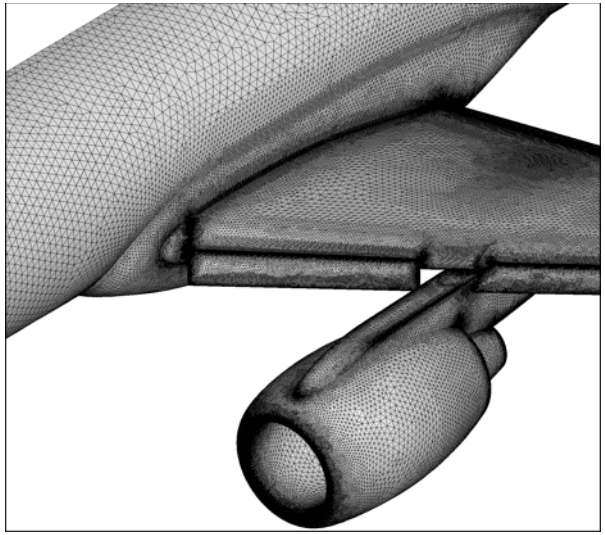


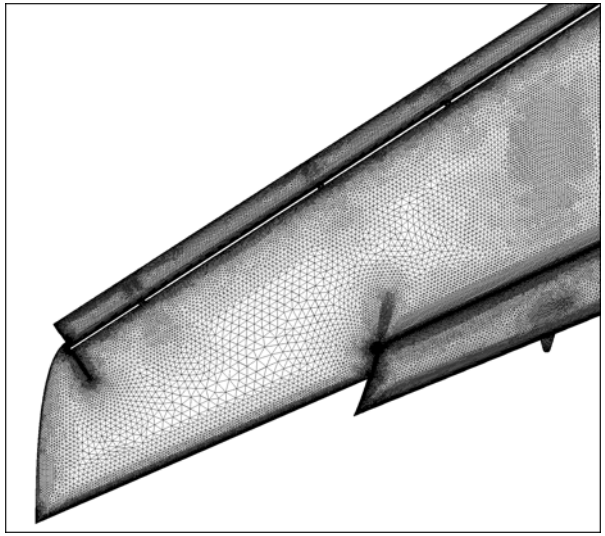


JSM grid comparison (PyNa On): C2, E

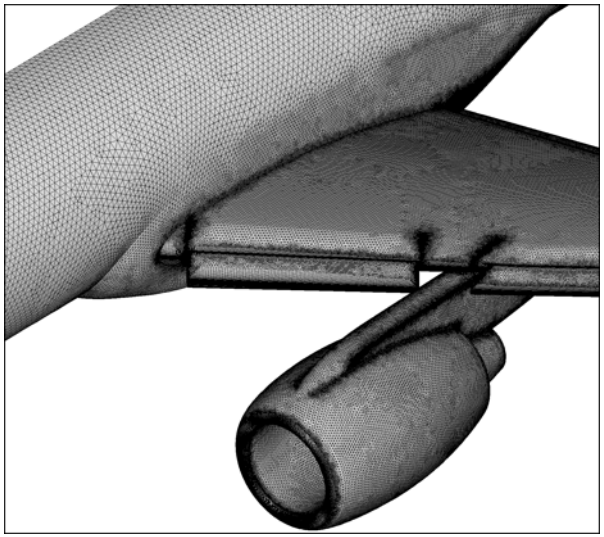


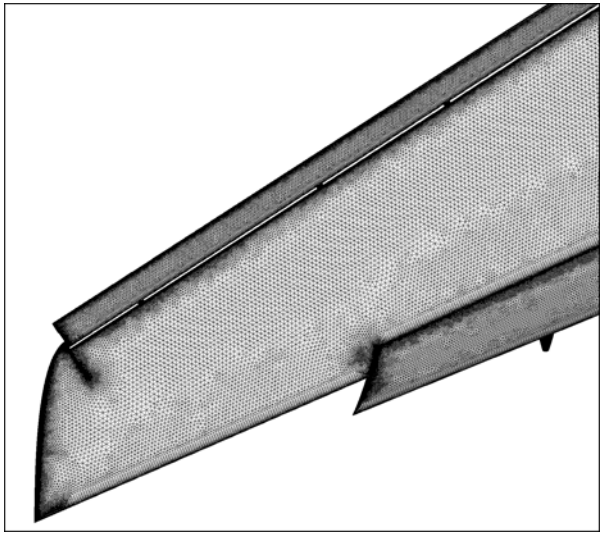
C2





E





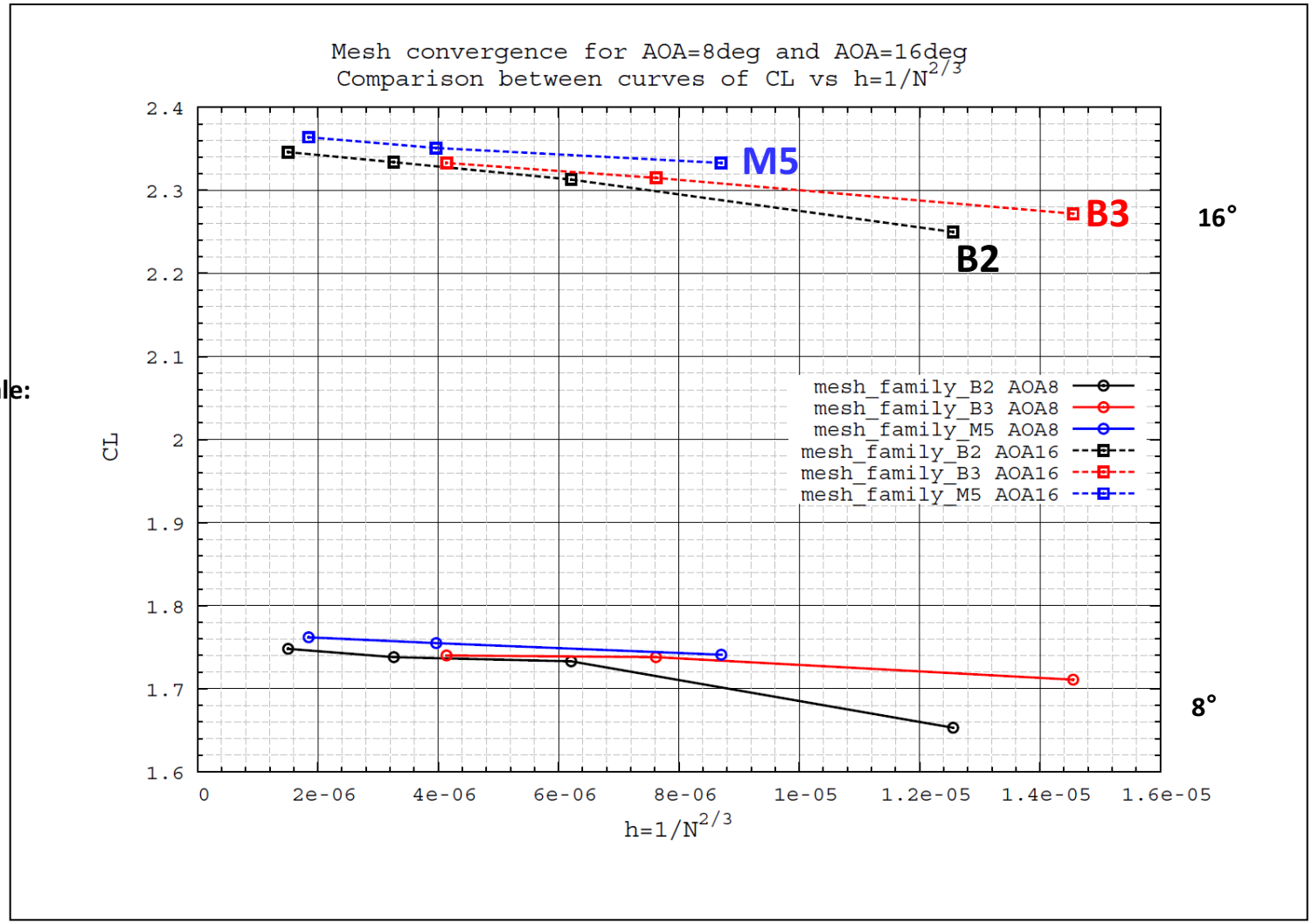
HL-CRM results

M=0.20

Rey=3.26E+06

HL-CRM results – grid convergence – CFD++

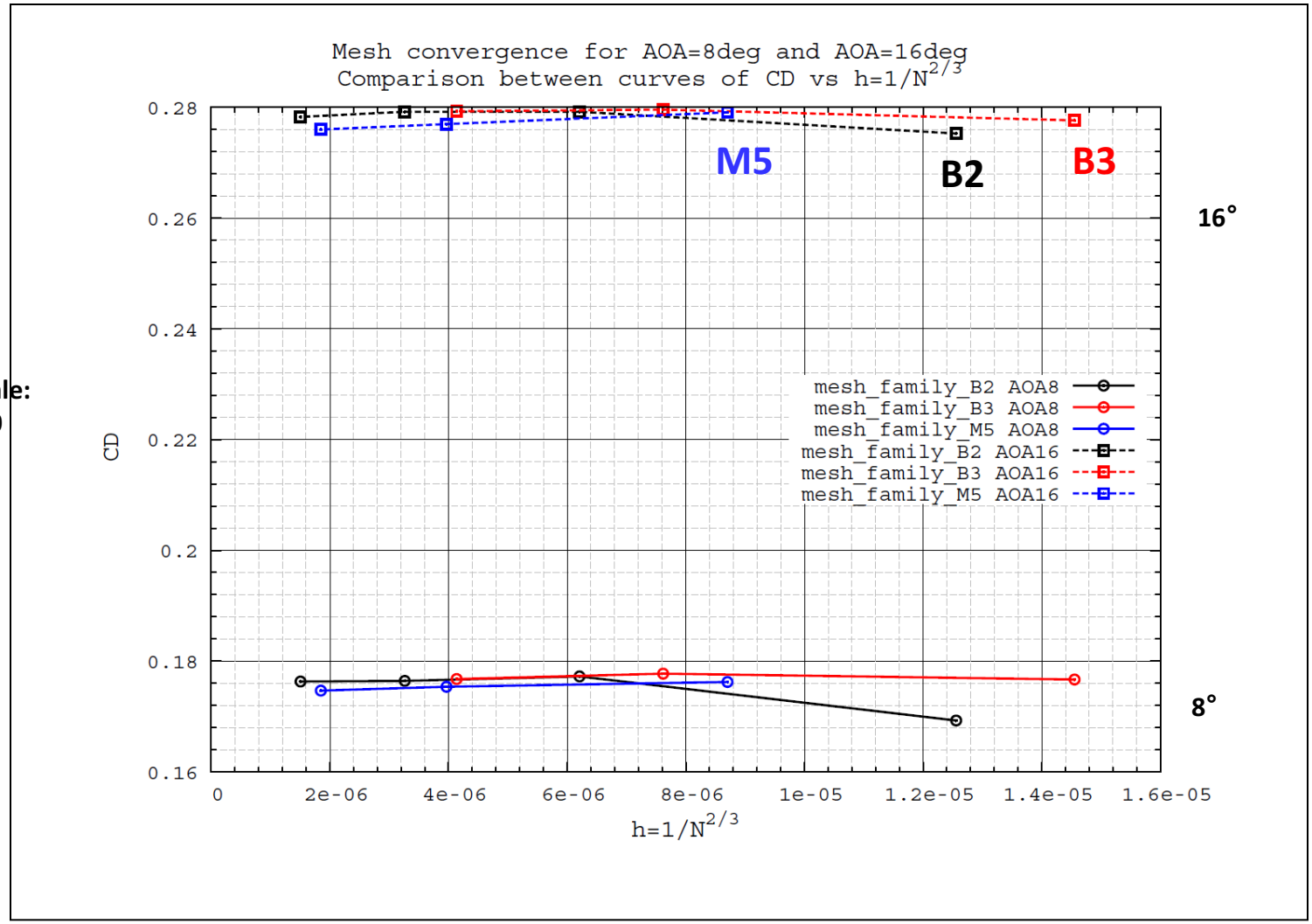
Grids B2, B3, M5



Small scale: 0.02

HL-CRM results – grid convergence – CFD++

Grids B2, B3, M5

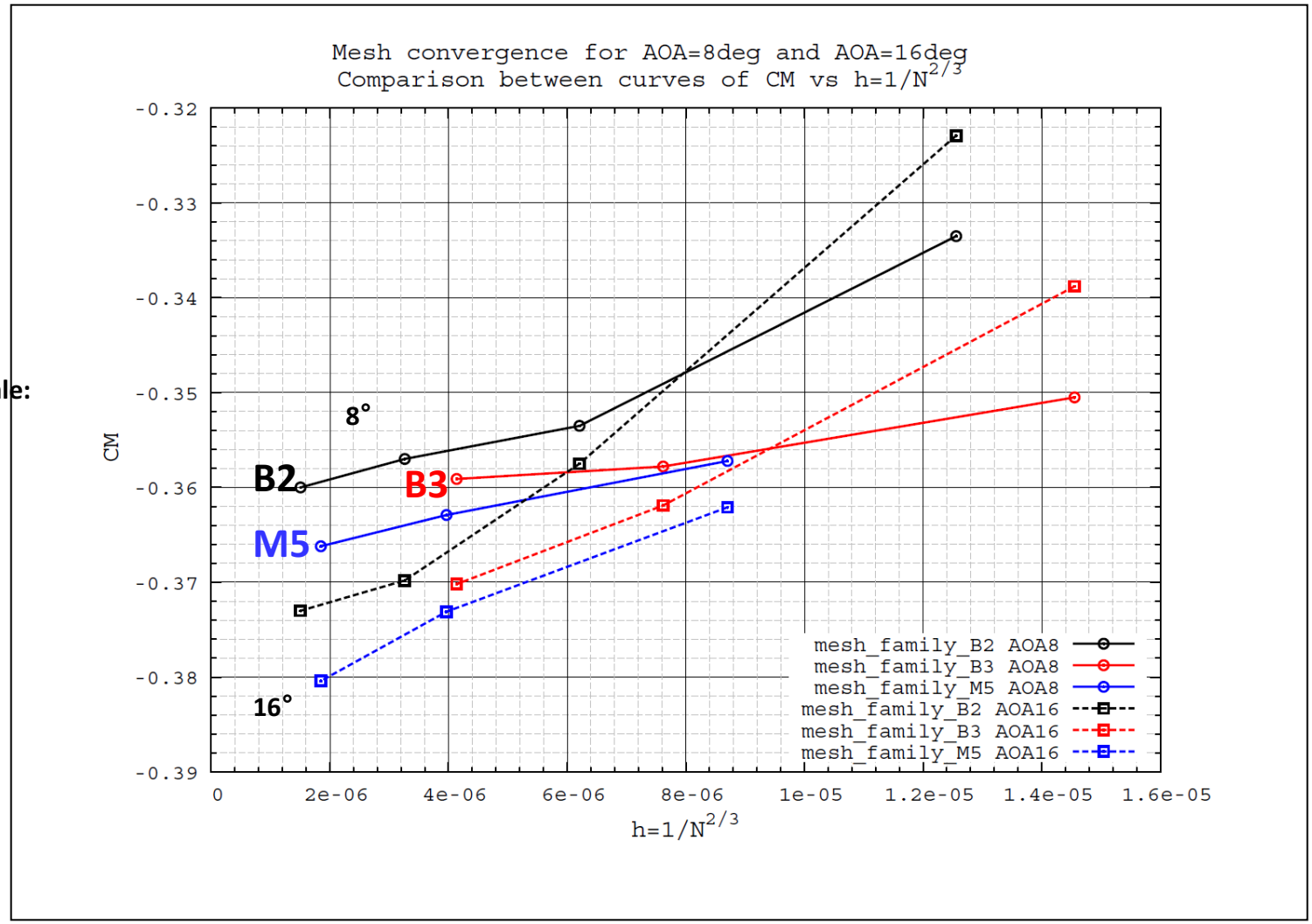


Small scale: 0.0040

HL-CRM results – grid convergence – CFD++

Grids B2, B3, M5

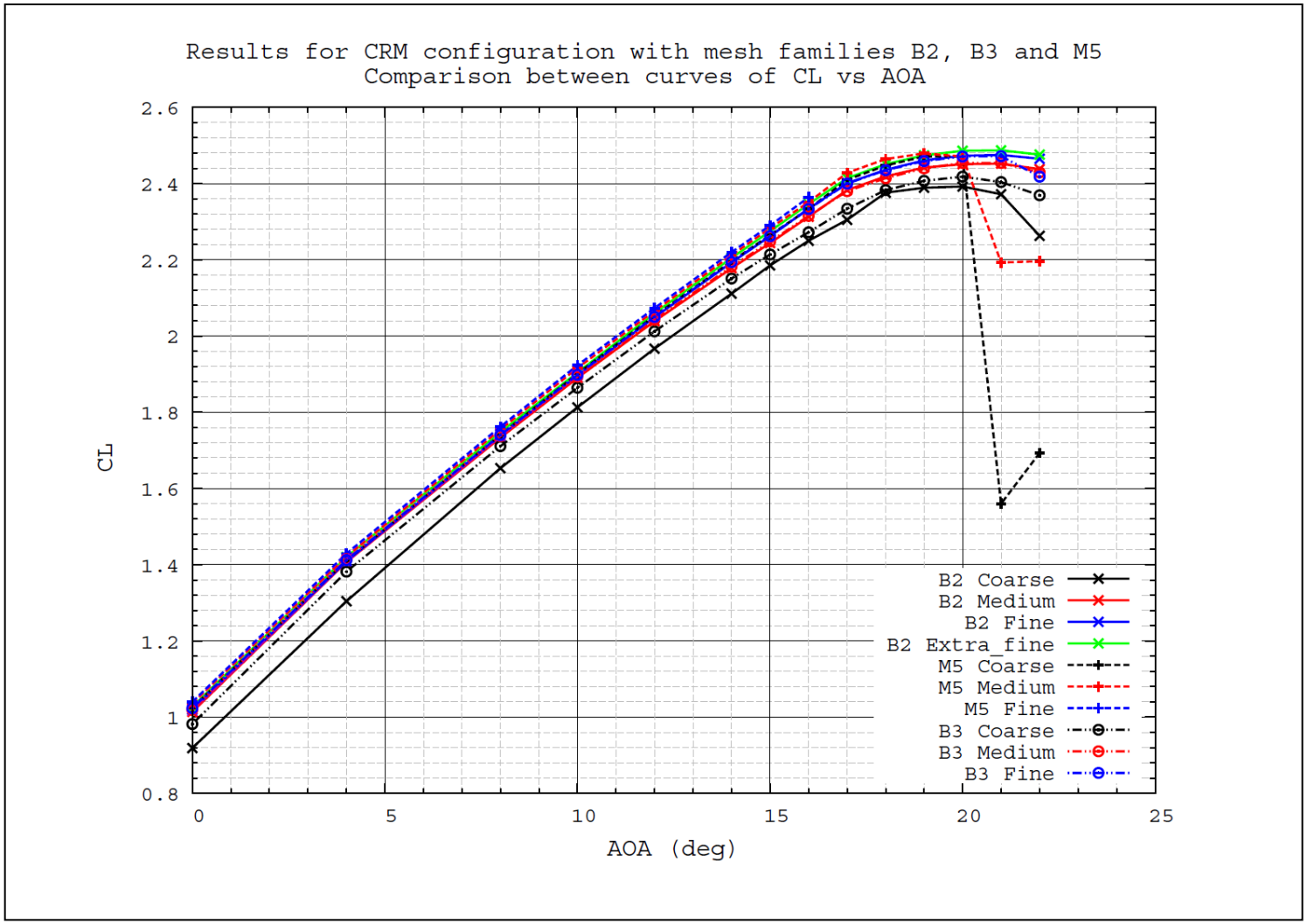
Small scale: 0.002



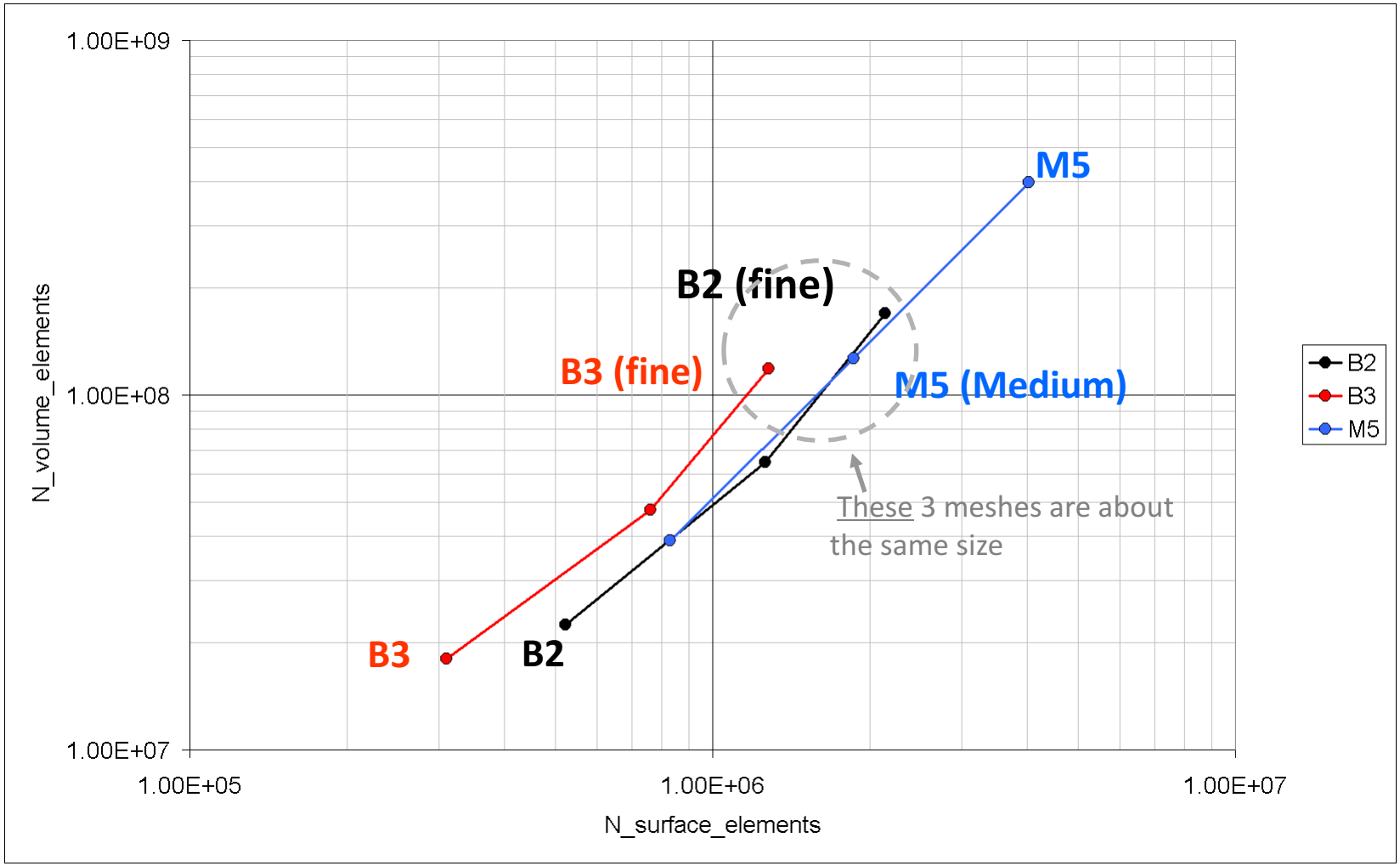
Flow separation position and extent strongly affect CM

HL-CRM results – coefficients – CFD++

Grids B2, B3, M5

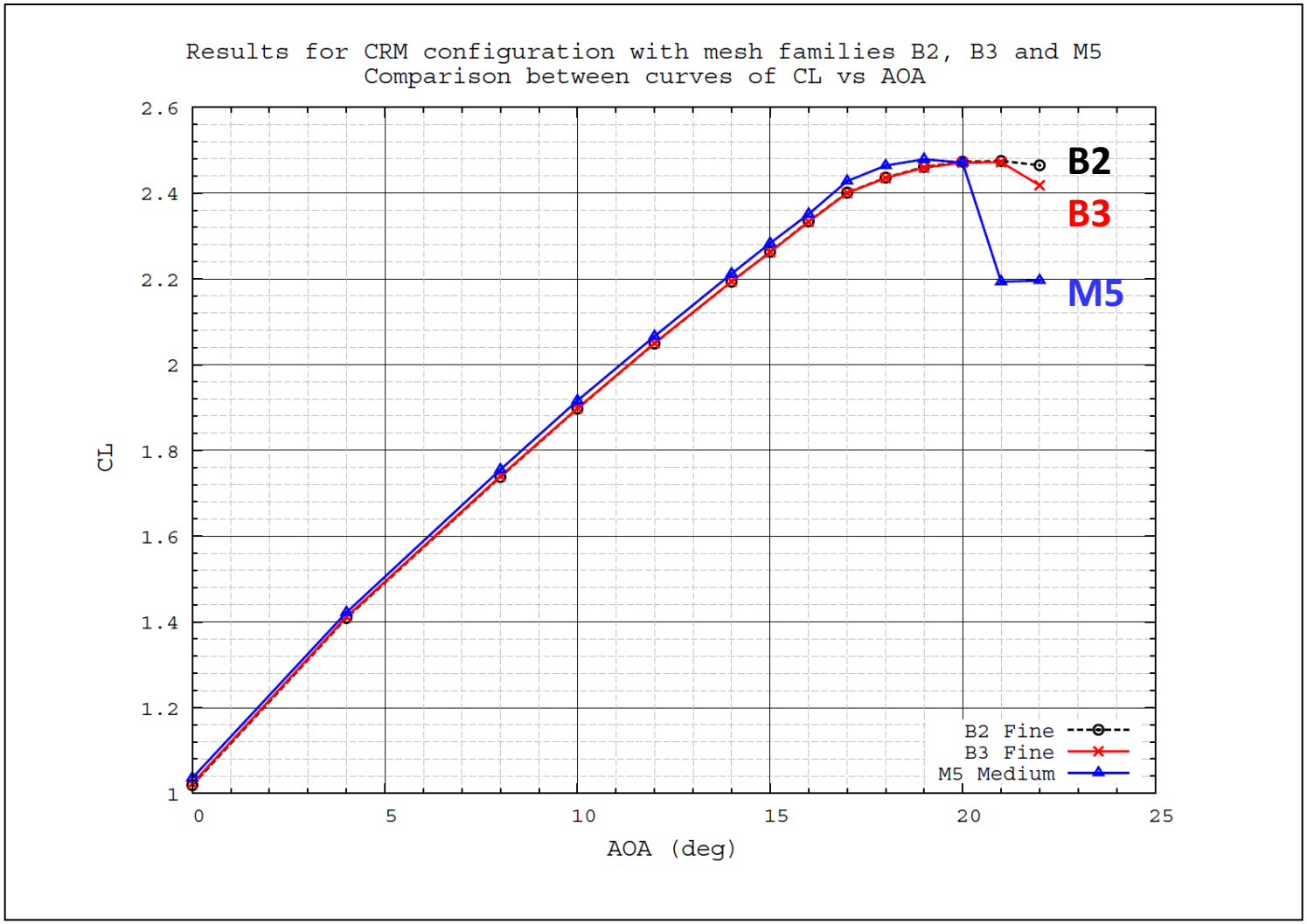


Grid comparison: B2, B3, M5



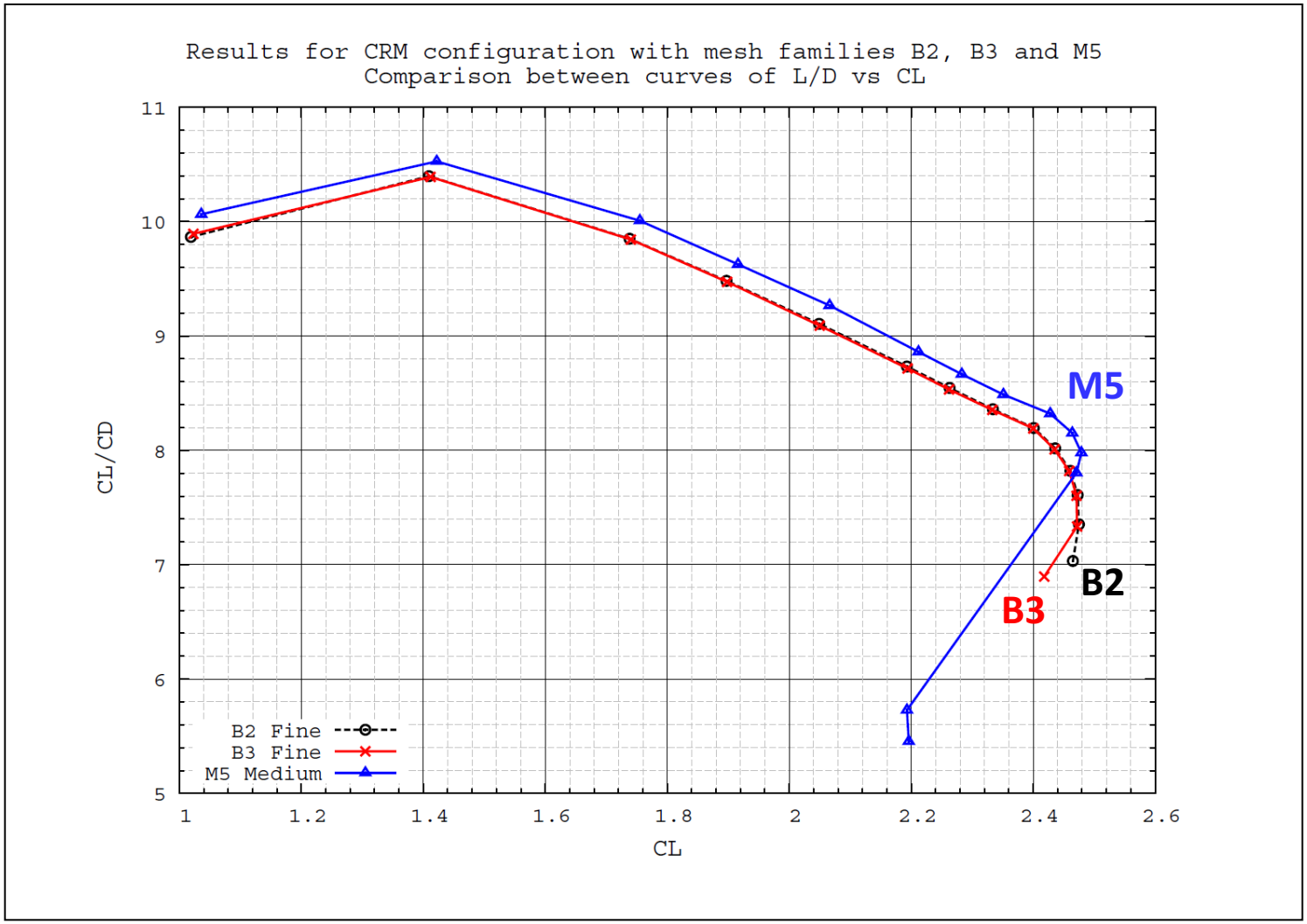
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5



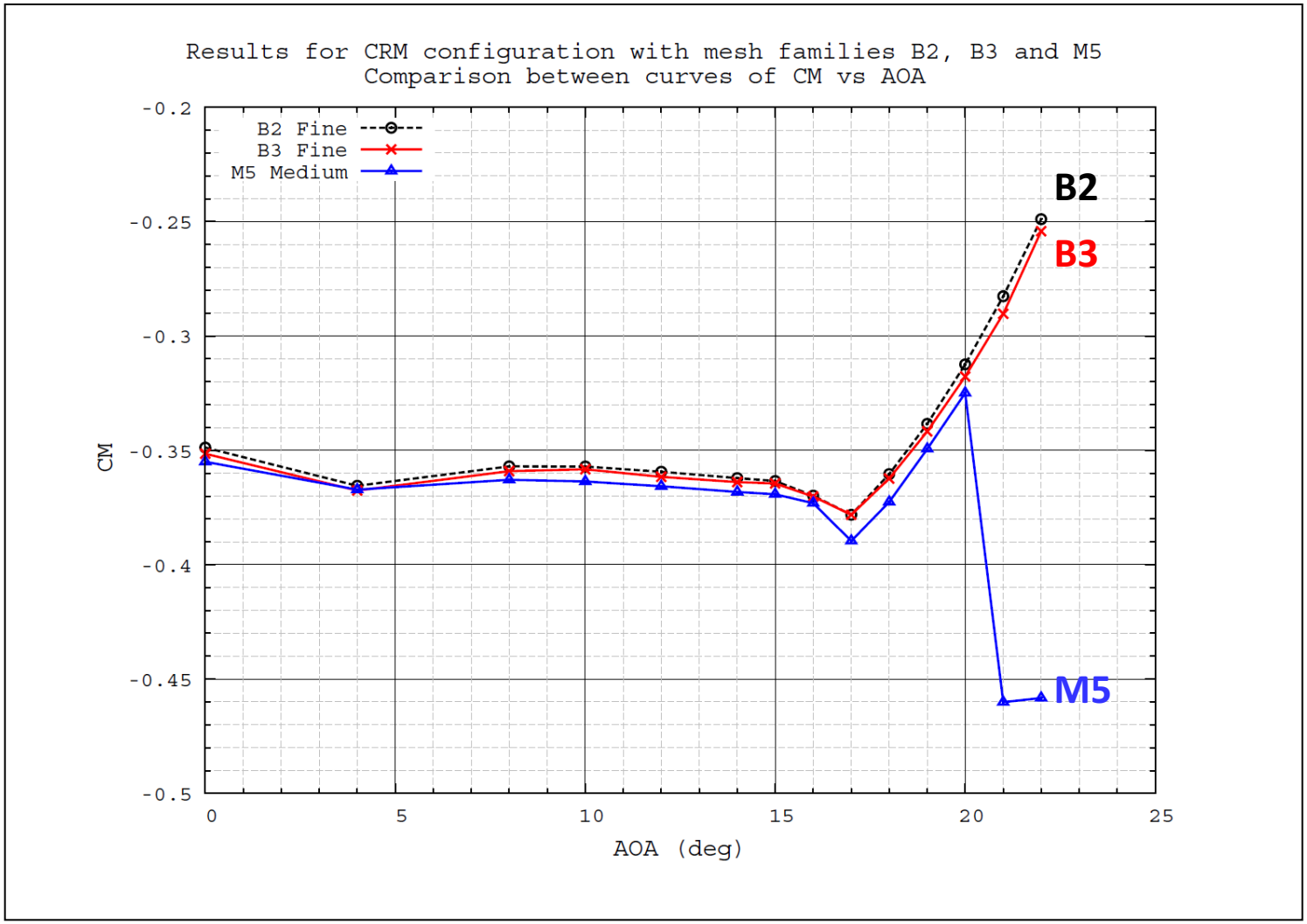
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5



HL-CRM results – coefficients – CFD++

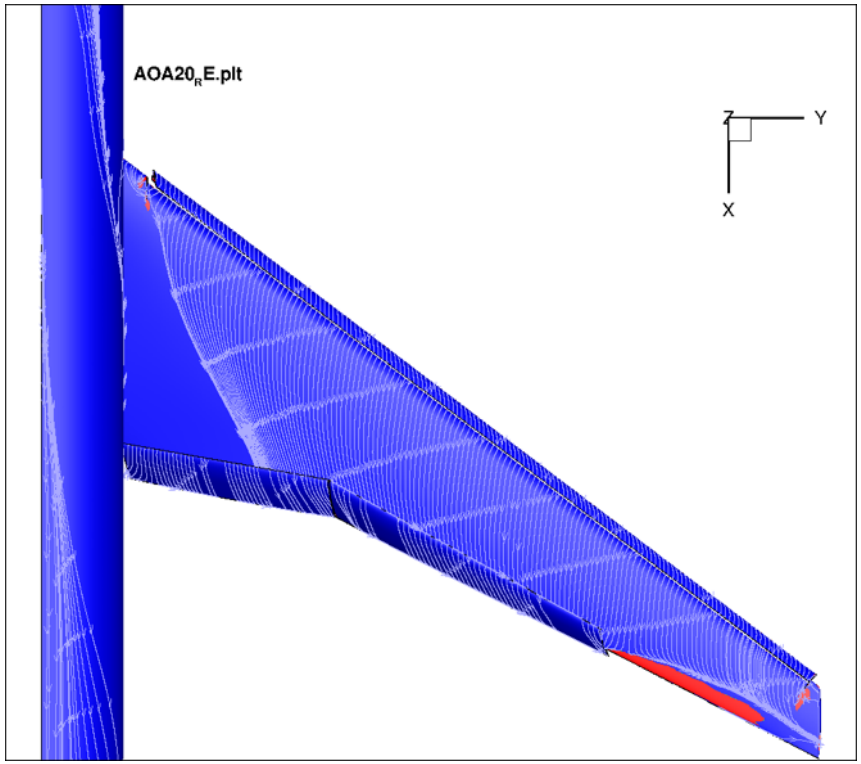
Grids B2, B3, M5



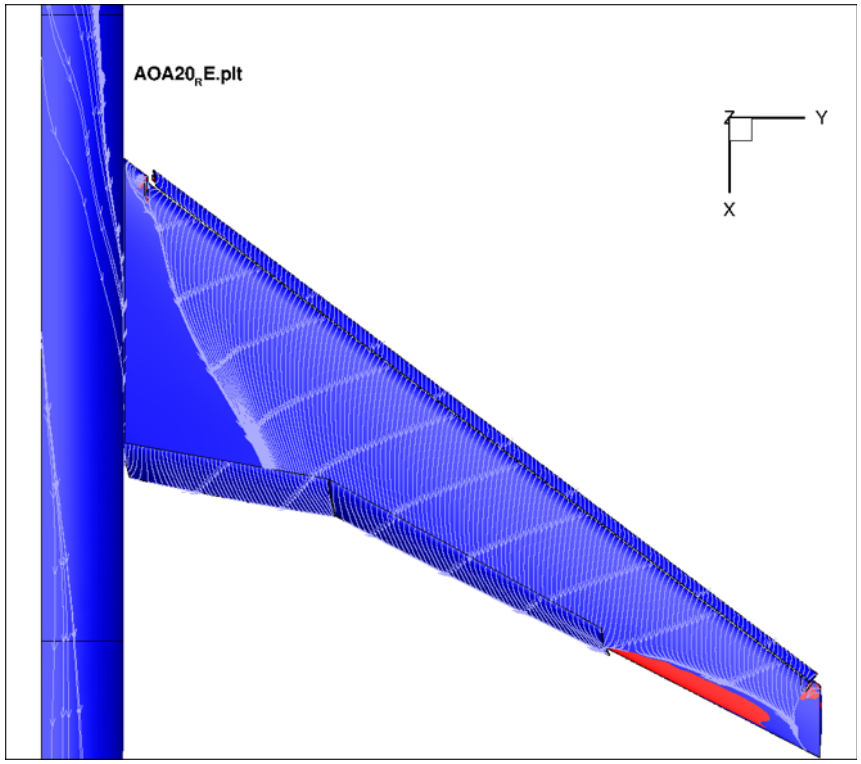
HL-CRM results – 20° – CFD++

Grids B2 fine x M5 medium

B2



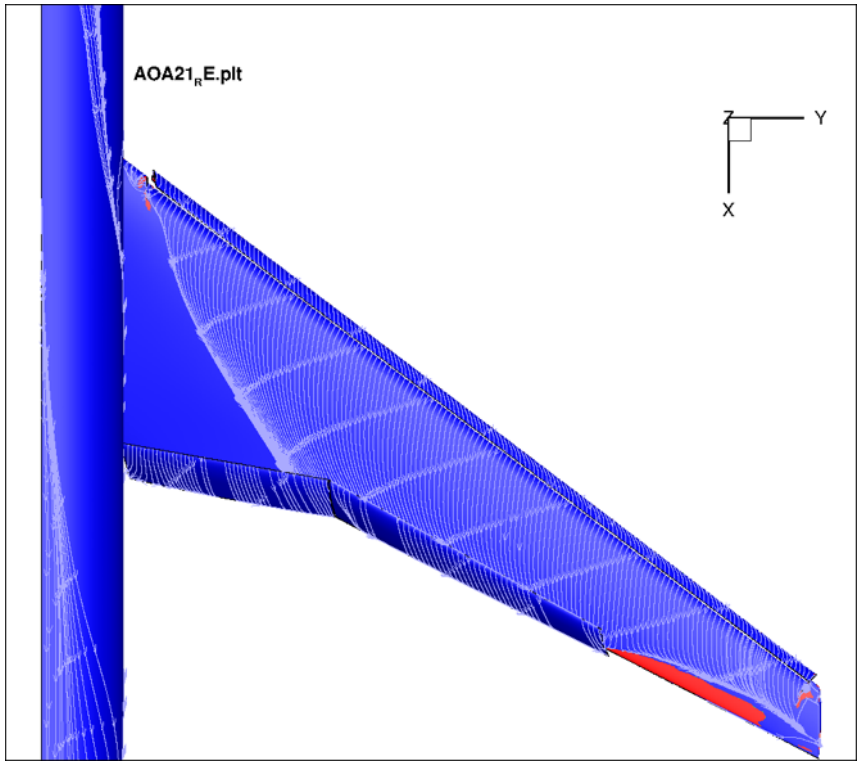
M5



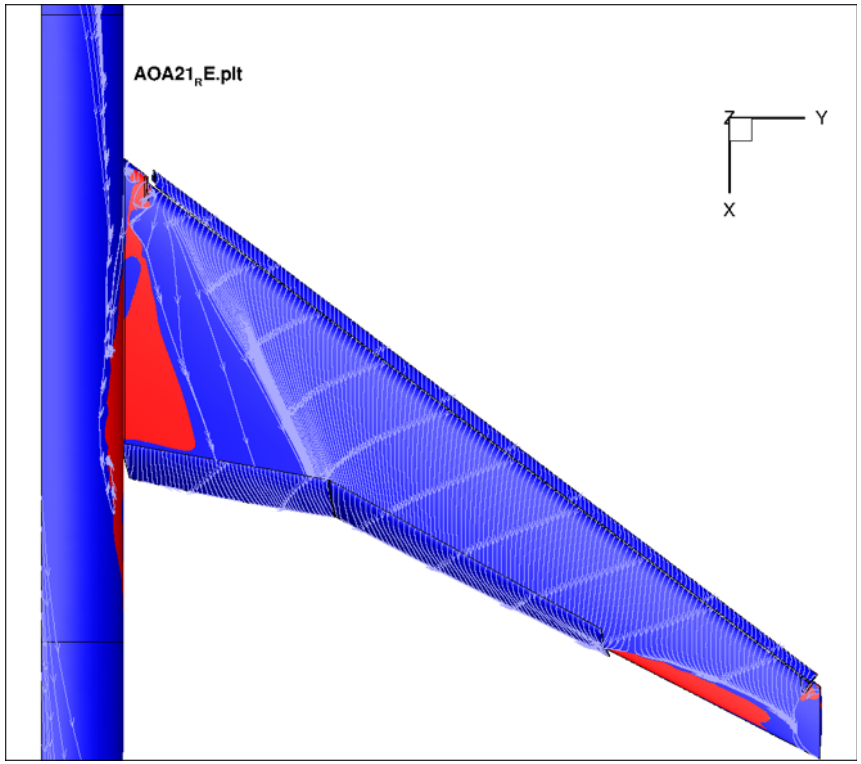
HL-CRM results – 21° – CFD++

Grids B2 fine x M5 medium

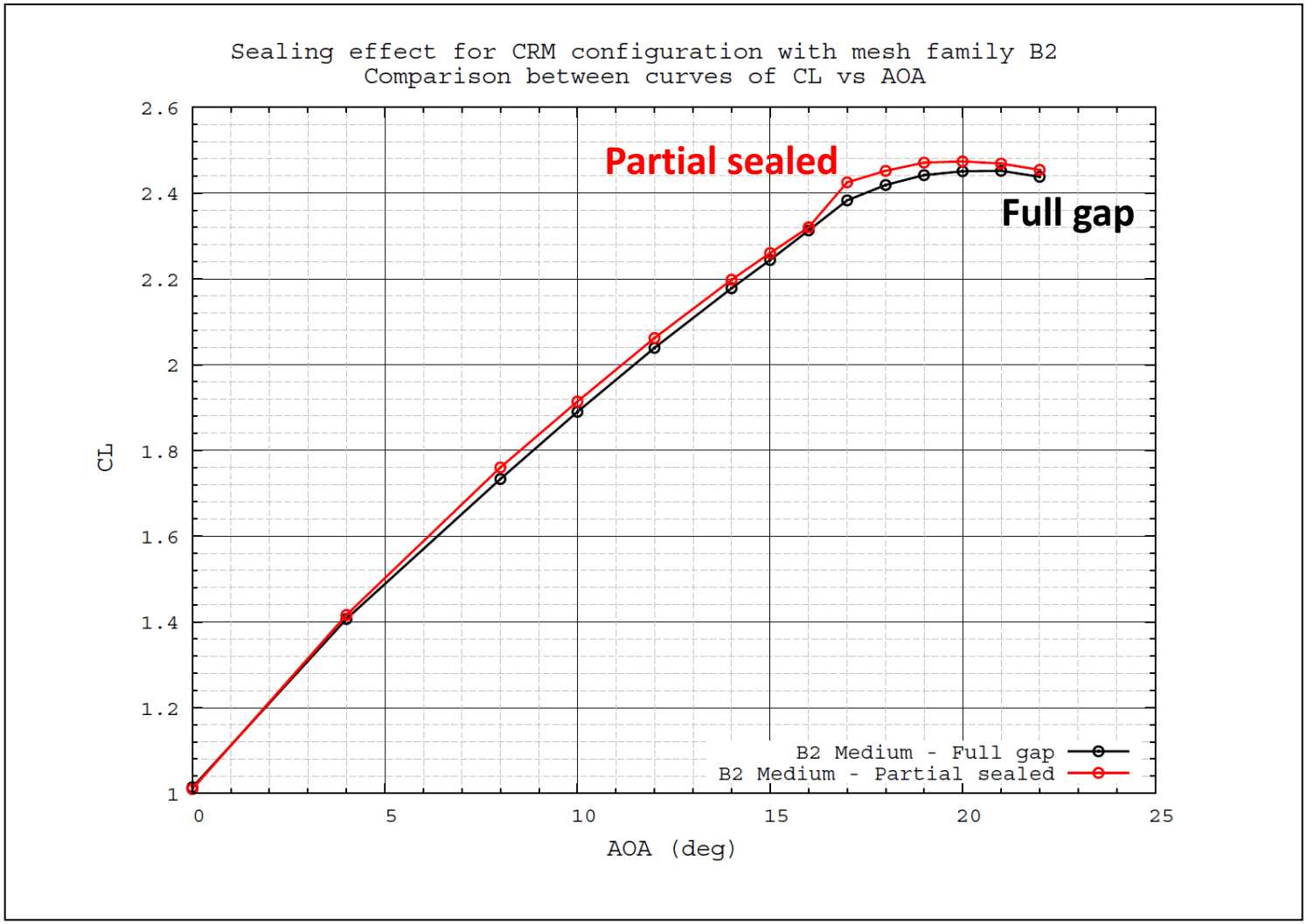
B2



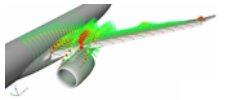
M5



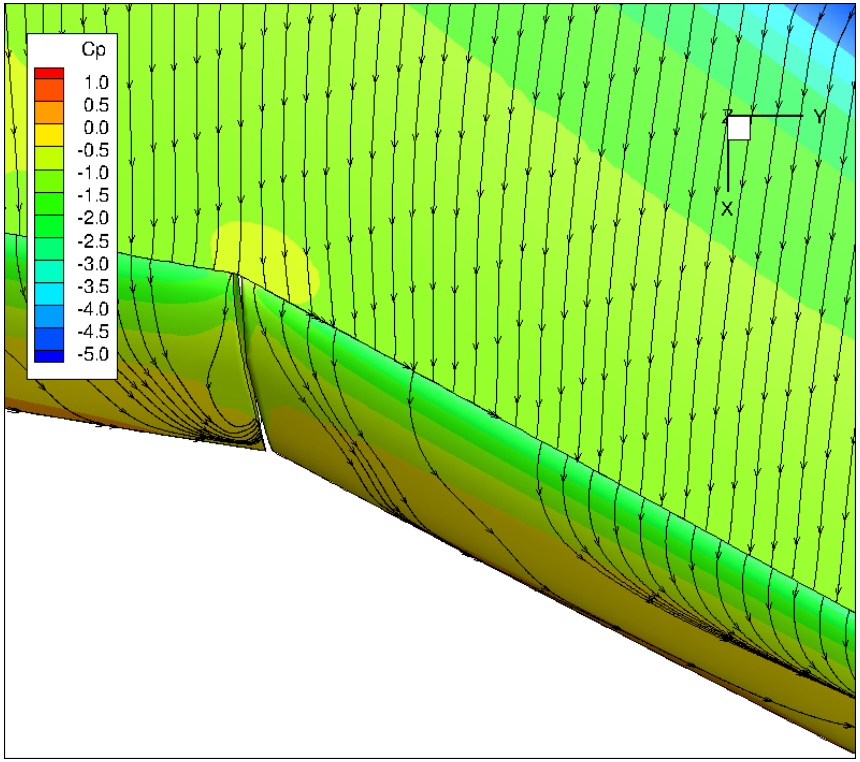
HL-CRM results – partial sealed x full gap

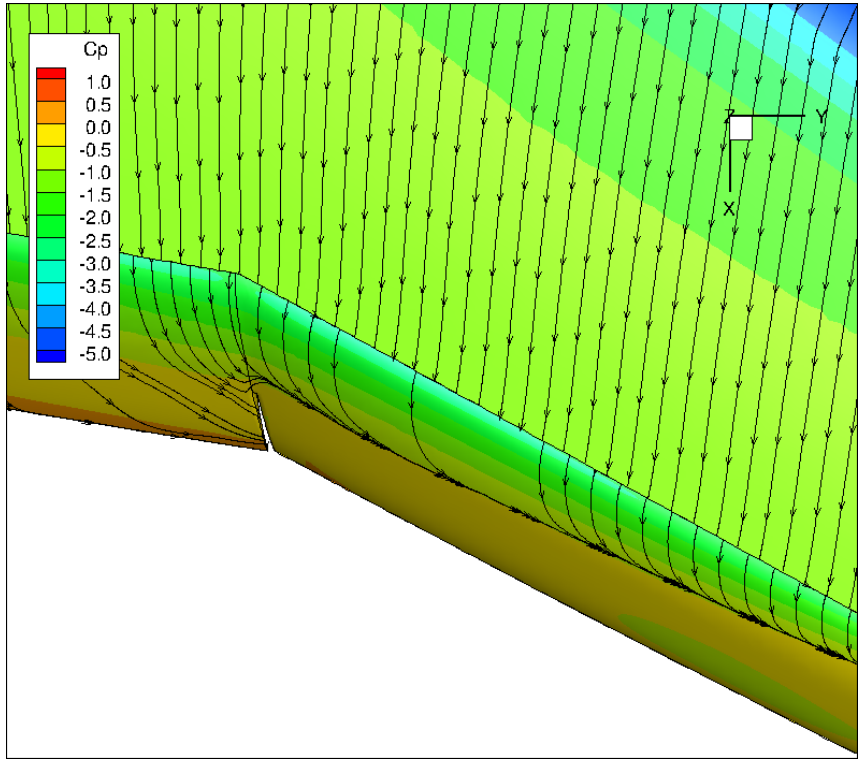


HL-CRM results – partial sealed x full gap – flow visualization

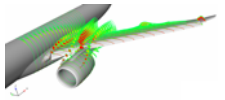


AOA=16°

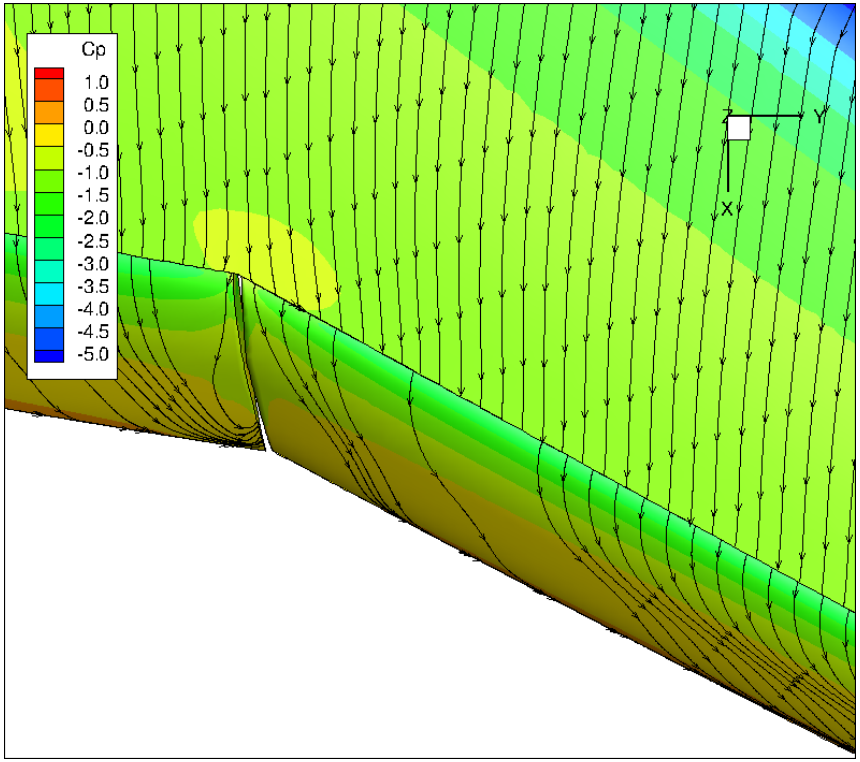


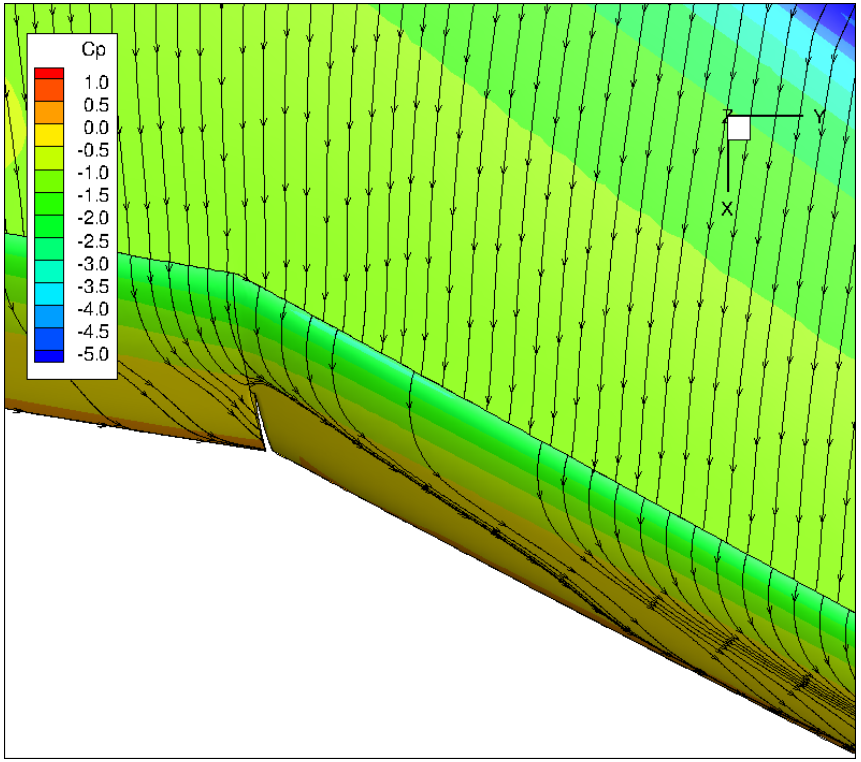


HL-CRM results – sealed gap x non-sealed – flow visualization

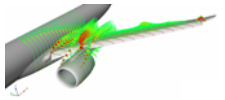


AOA=17°





Brief overview of HL-CRM results



- Grid convergence
  - Grid M5 seems to converge to a lower value of CD and more negative CM (due to a smaller flow separation on flap)
    - Uniform surface grid distribution
  - Results are reasonably converged for 8° but still show some variation at 16°
- Coefficients
  - Grids B2 and B3 (Fine mesh) yield virtually the same results for CL and CD, with grid B3 having less elements
  - Grid M5 captured an inboard stall at 20°, while grids B2 and B3 captured outboard stall
- Partial seal
  - Overall, the seal increases CL, CM (more negative) and L/D ratio
  - The partial seal caused an increase in flow separation at 16° on the outboard flap that diminishes for larger angles-of-attack

JSM results

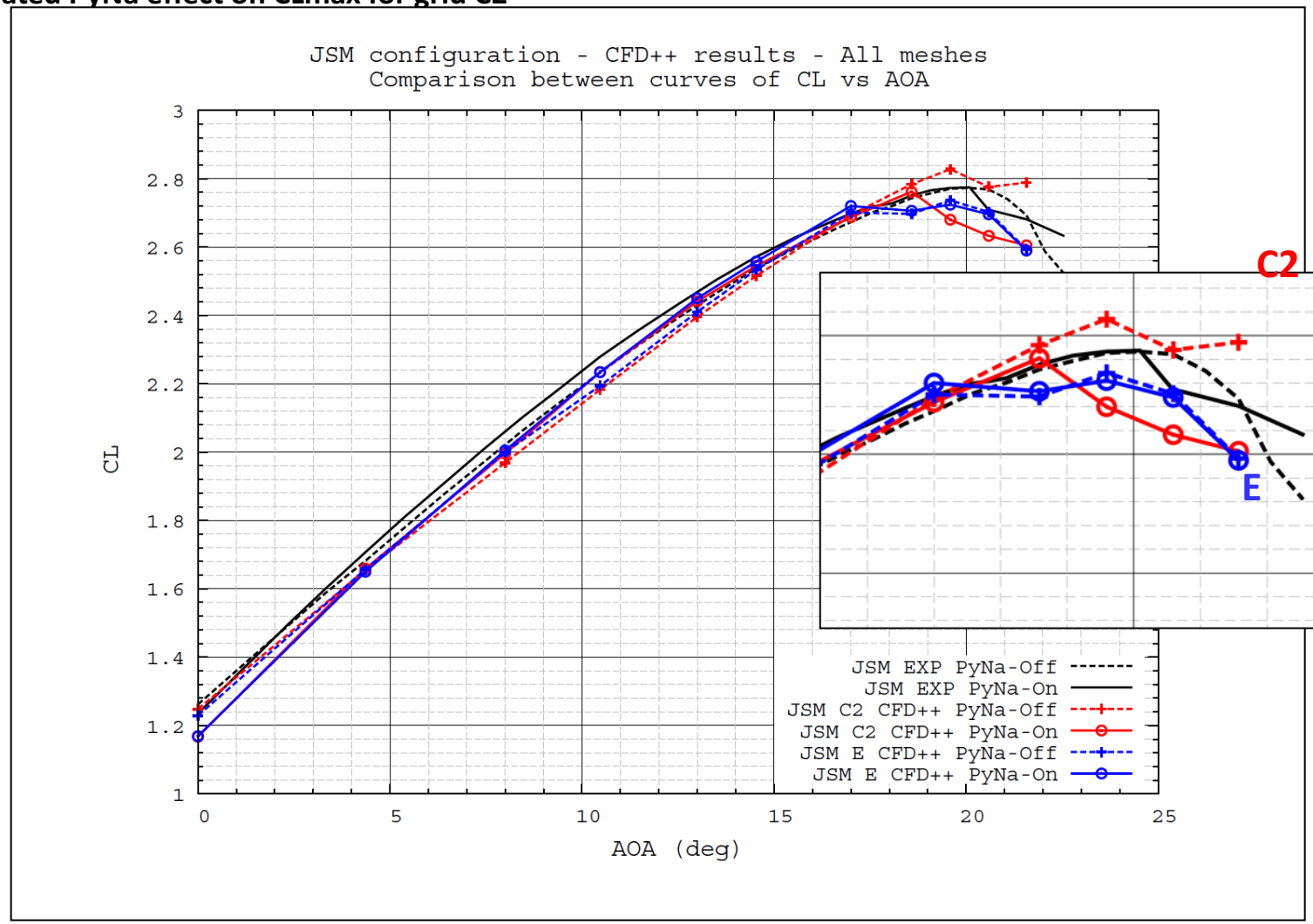
M=0.17

Rey=1.93E+06

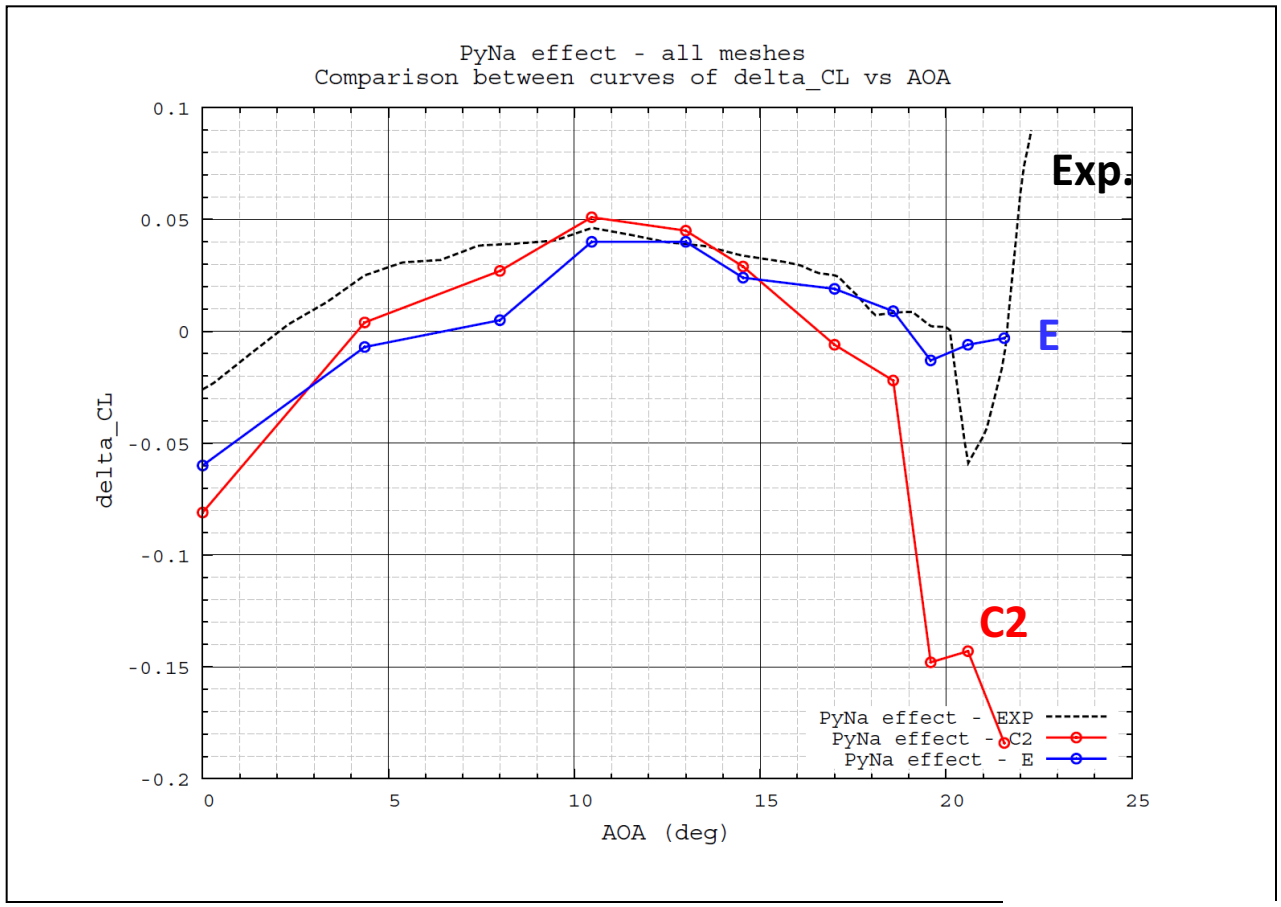
JSM results – PyNaOn x PyNaOff

Non-monotone behavior of CL near stall region for grid E

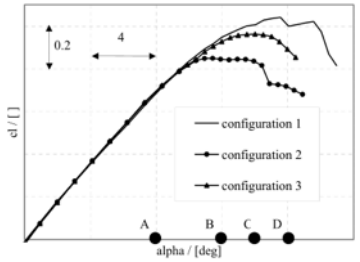
Exaggerated PyNa effect on CLmax for grid C2



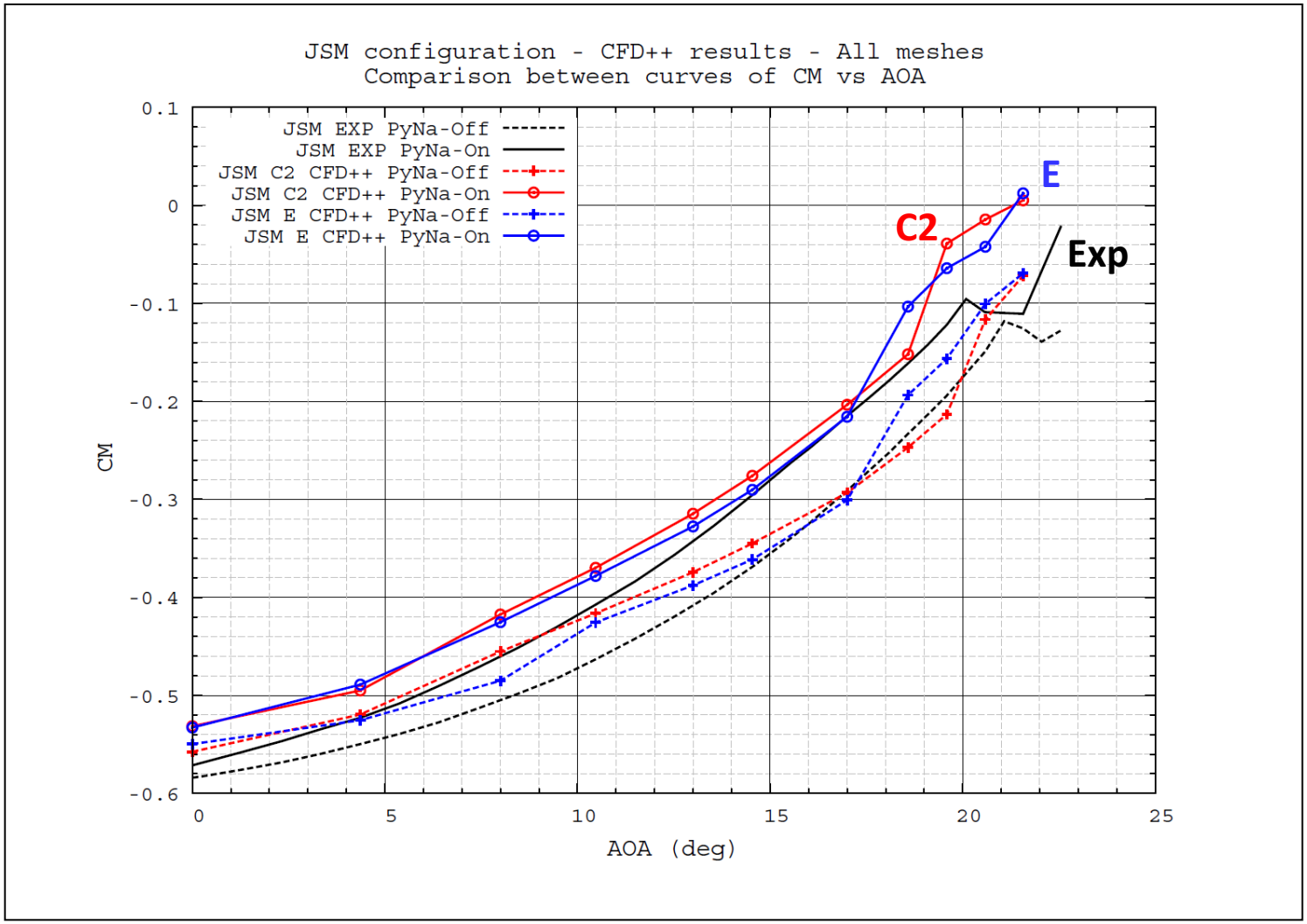
JSM results – DPyNaOn - PyNaOff



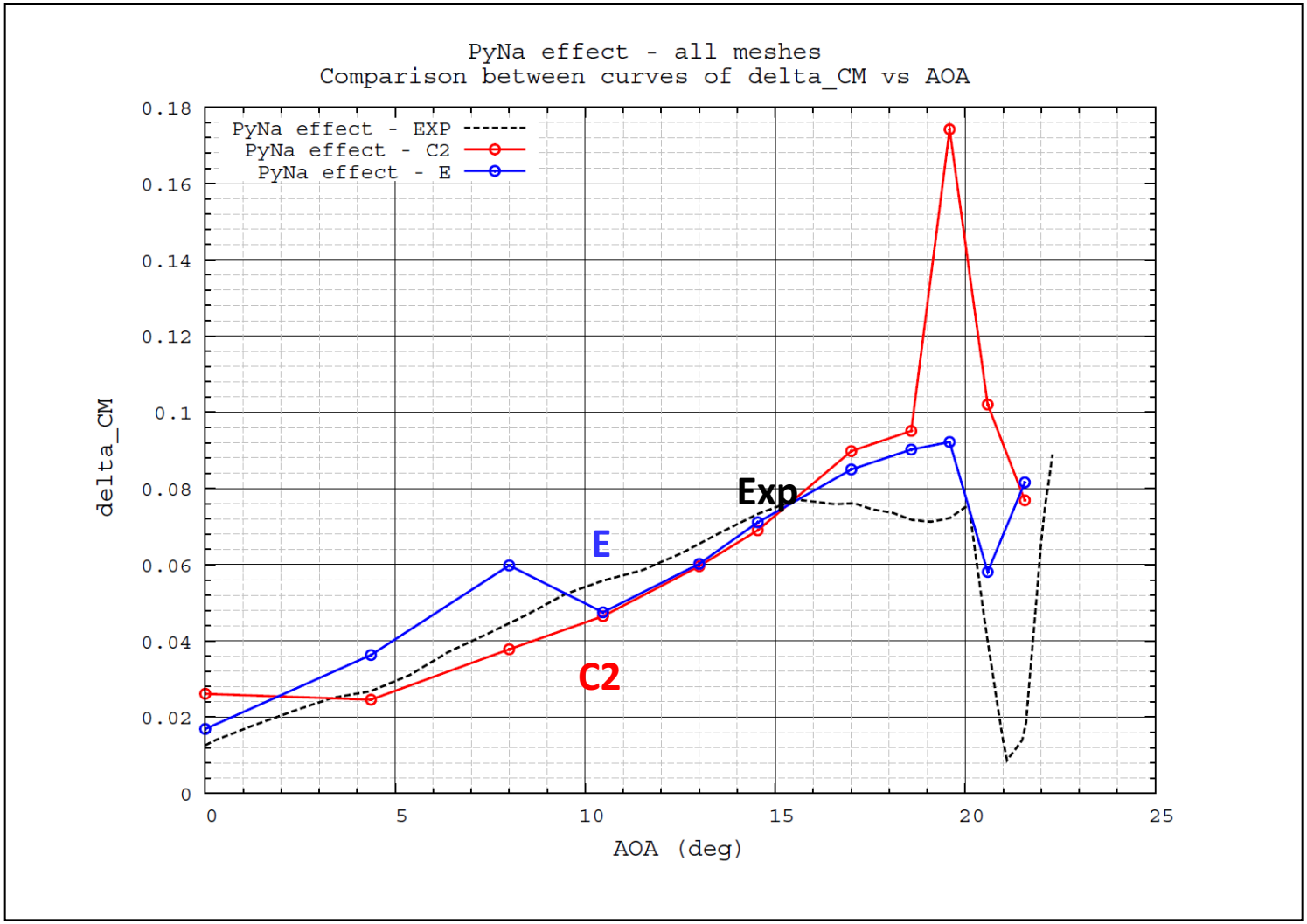
- **Captured small DCLmax**
  - **AIAA 2007-4298, Low Speed High Lift Validation Tests within the European Project EUROLIFT II, Quix H, Schulz M, Quest J, Rudnik R, Schröder A**
  - **The pylon-nacele can have much larger effects depending on the geometry**



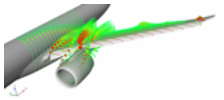
JSM results – PyNaOn x PyNaOff



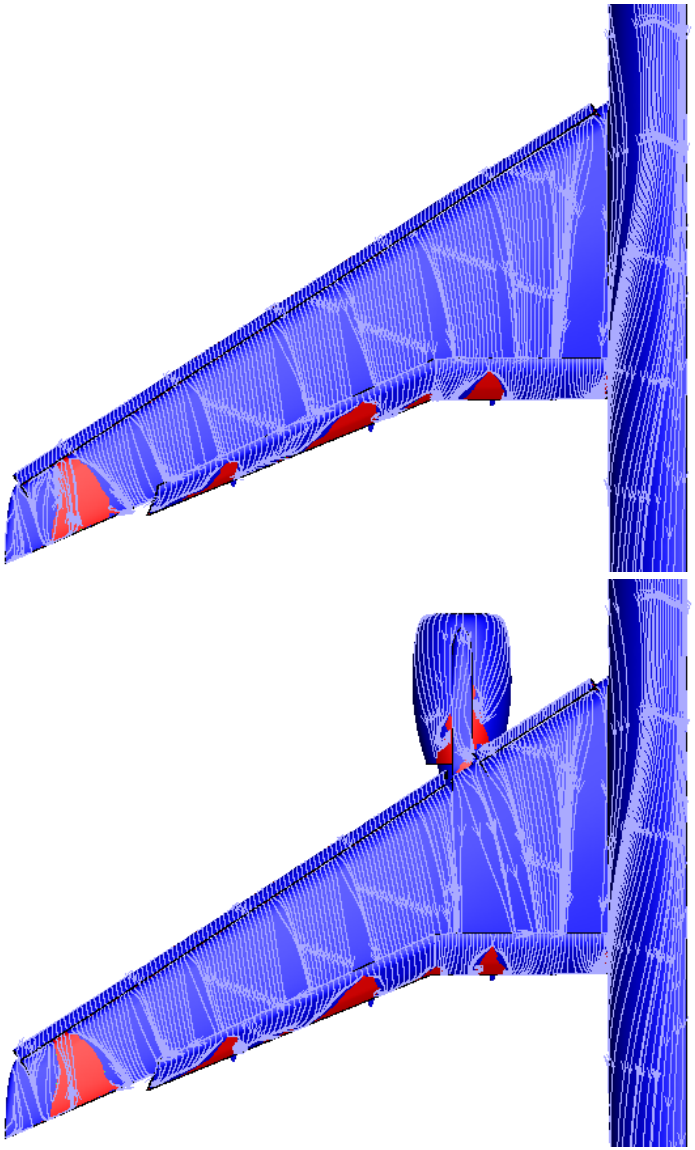
JSM results – DPyNaOn - PyNaOff



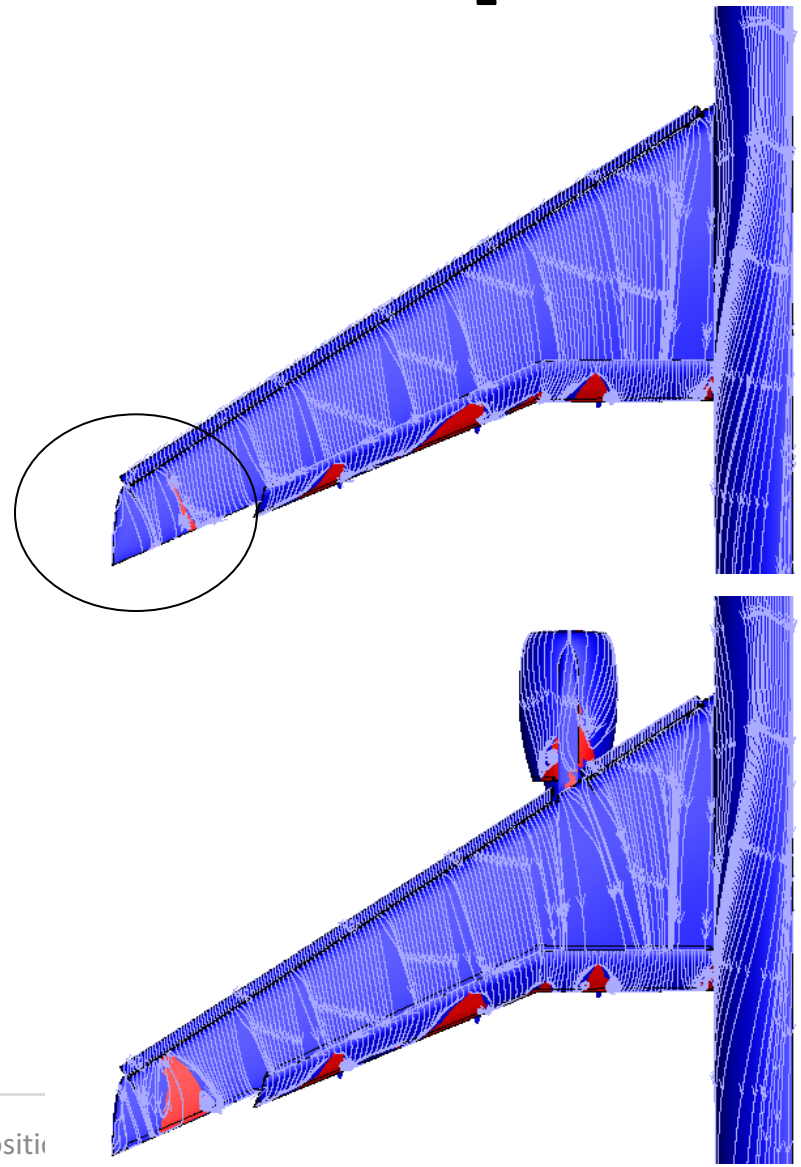
JSM results – PyNaOn x PyNaOff – 8°



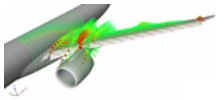
C2



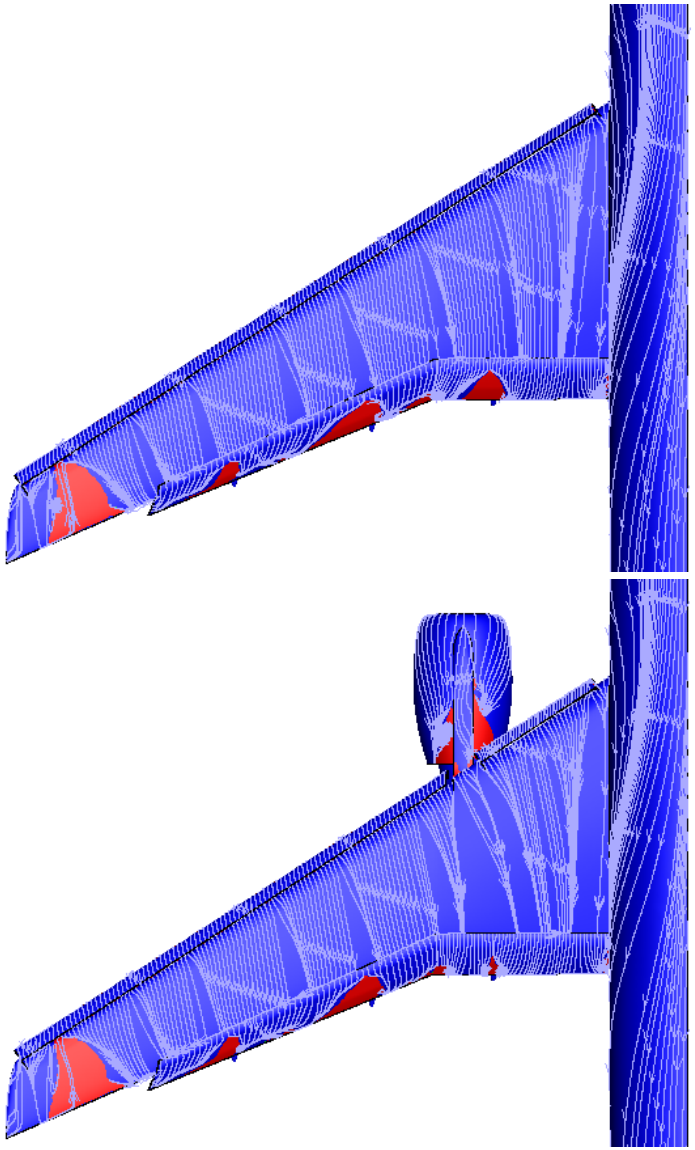
E



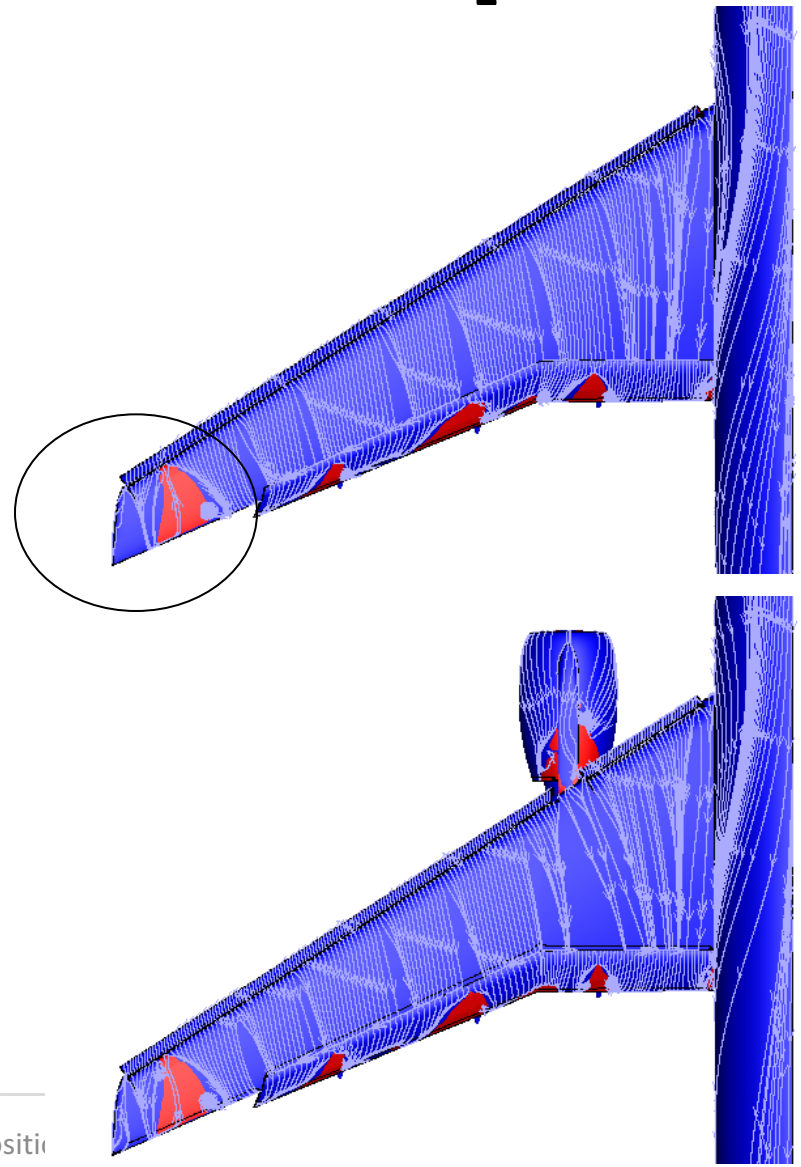
JSM results – PyNaOn x PyNaOff – 10°



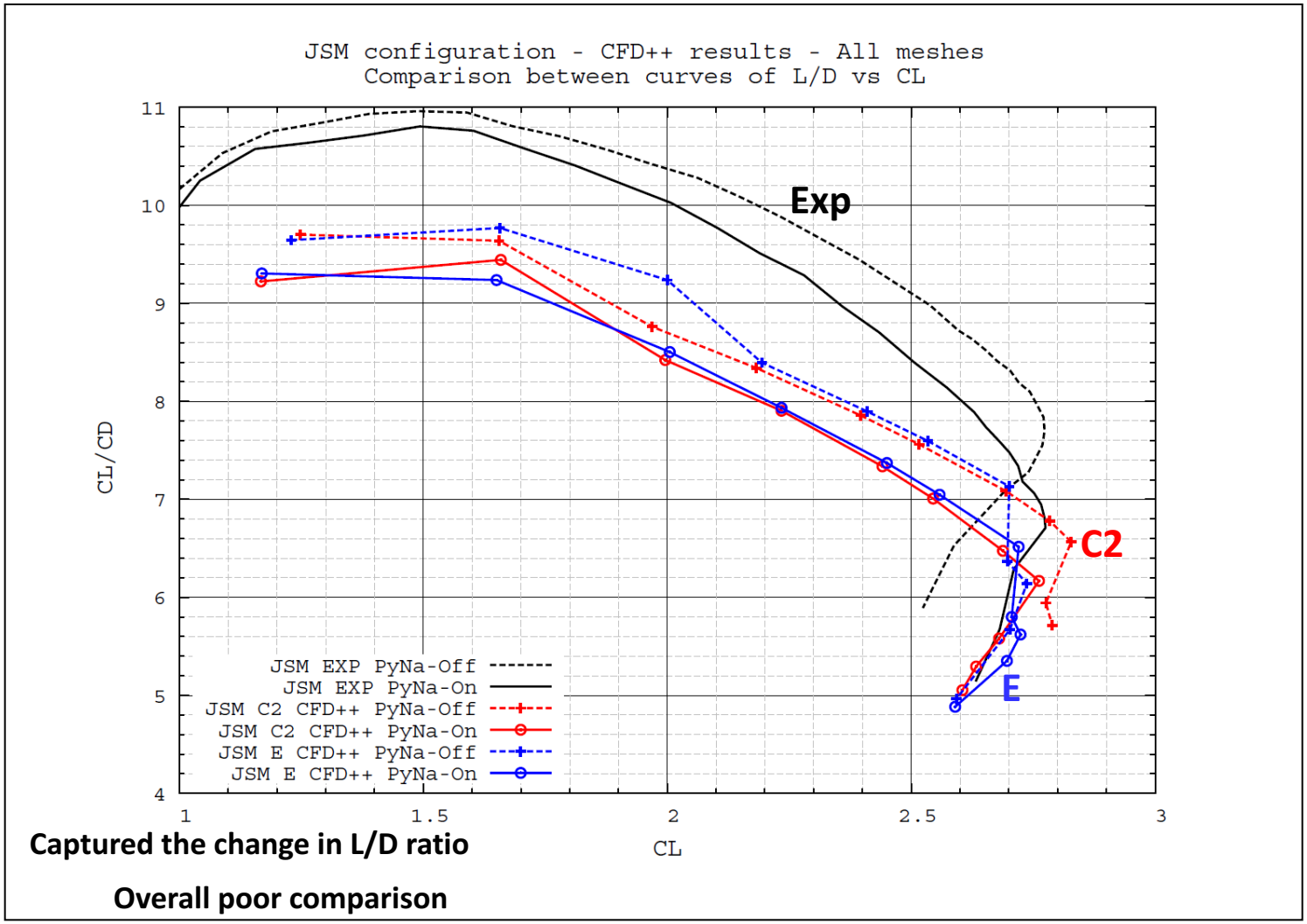
C2



E



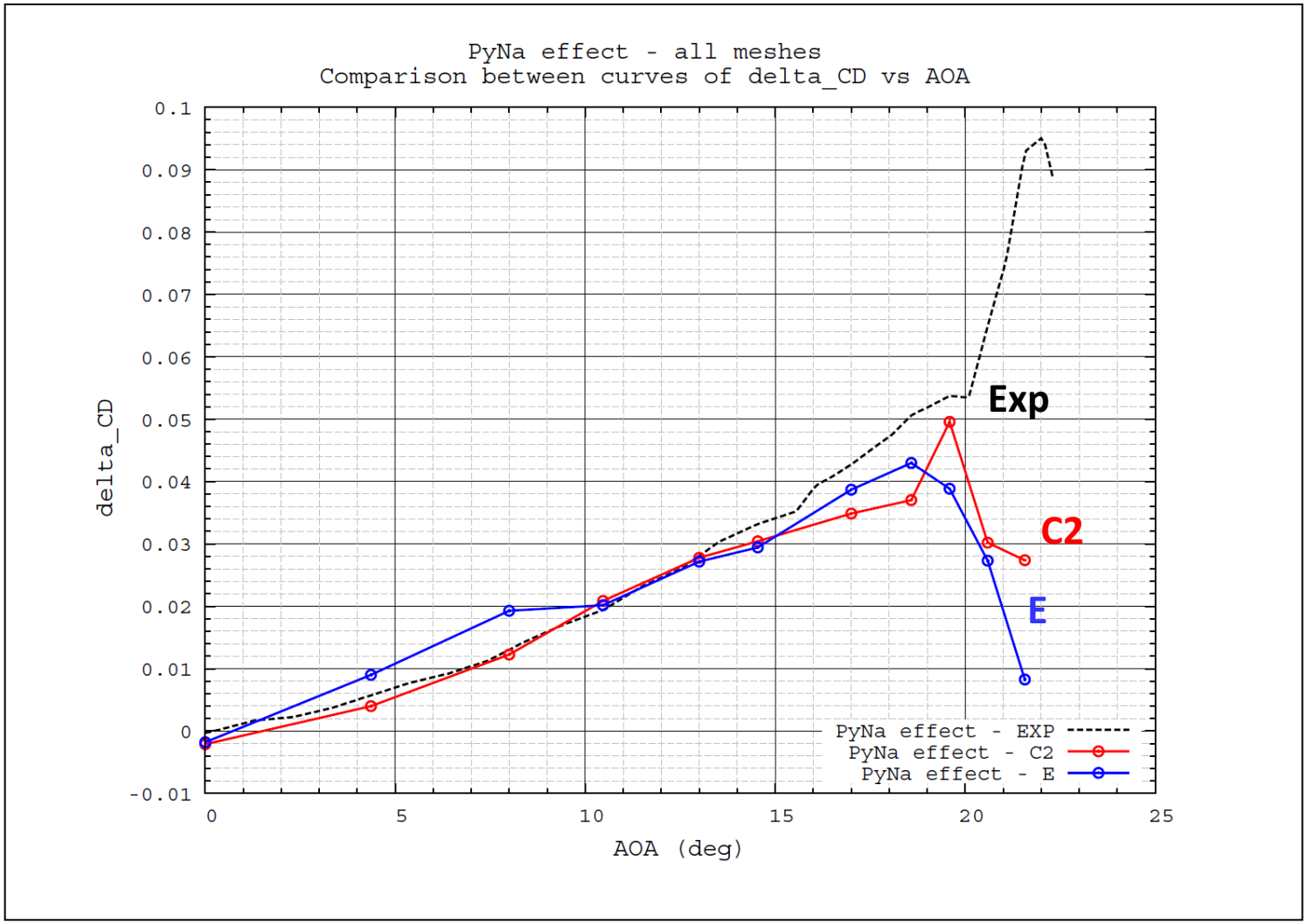
JSM results – PyNaOn x PyNaOff



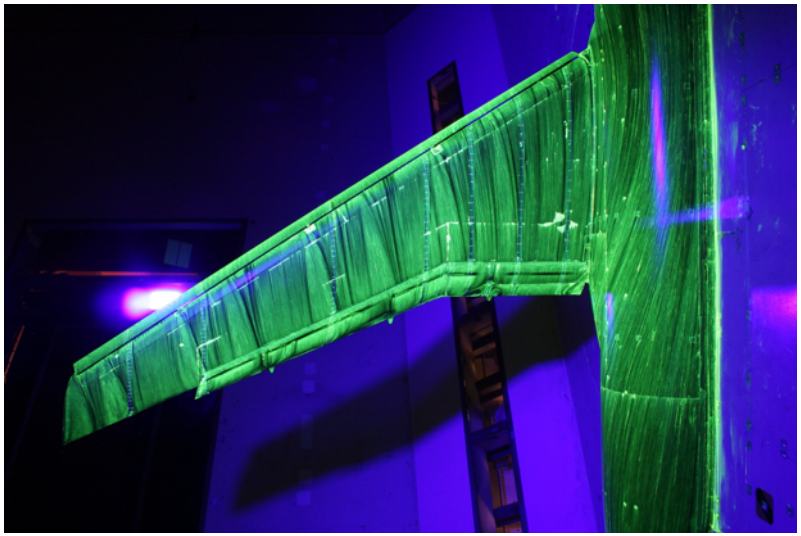
Captured the change in L/D ratio

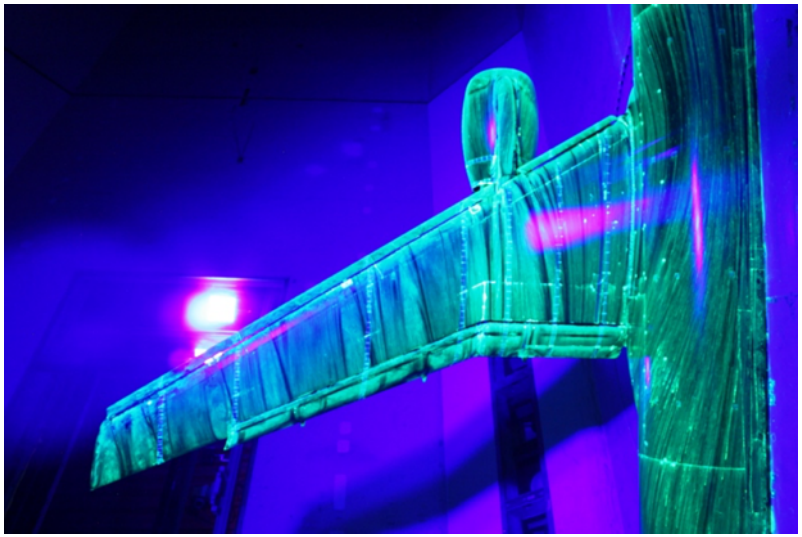
Overall poor comparison

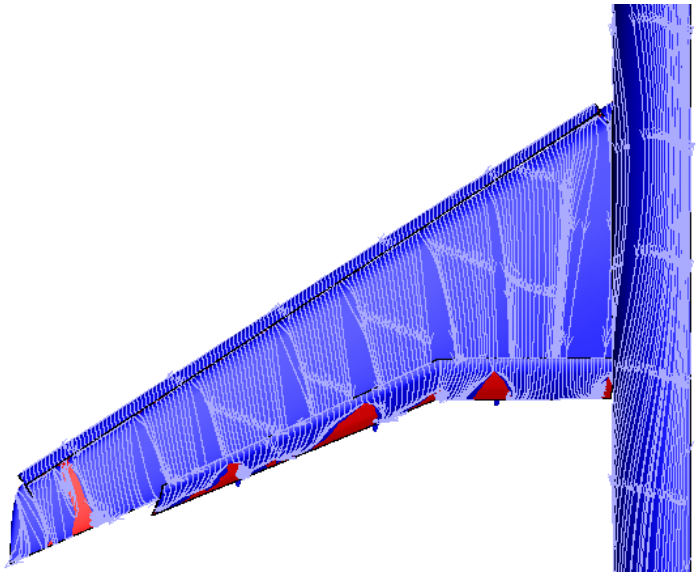
JSM results – DPyNaOn - PyNaOff

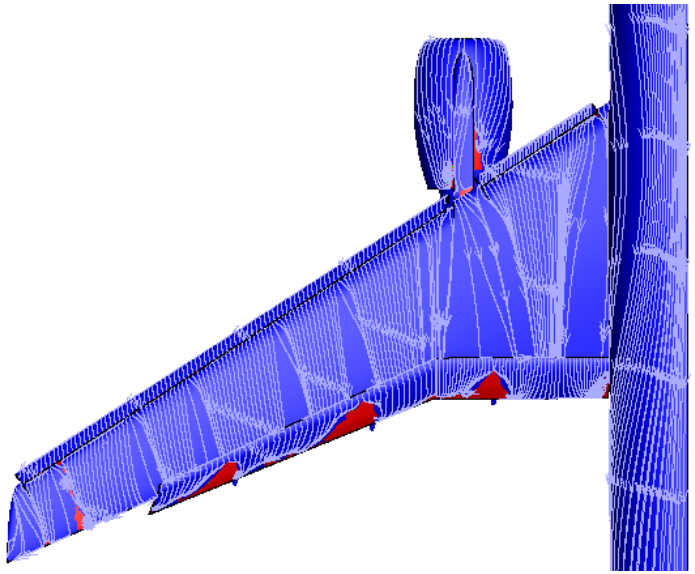


JSM results – C2 – PyNaOn x PyNaOff – 4.36°

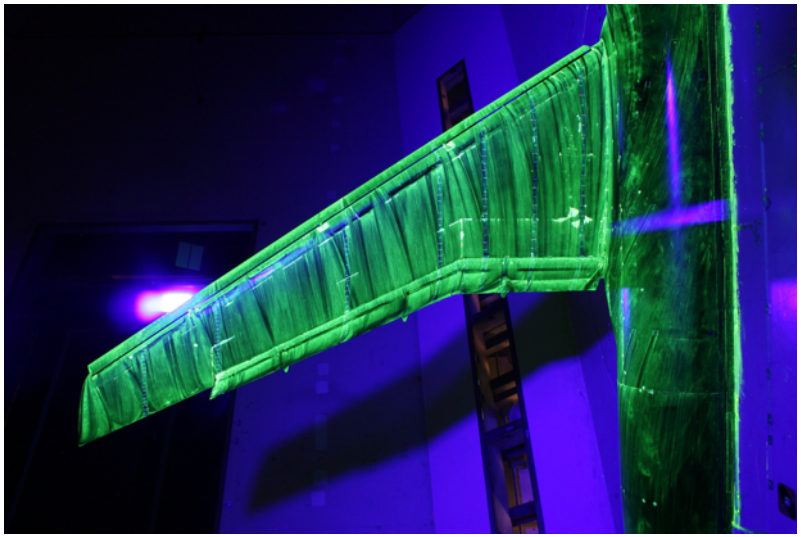


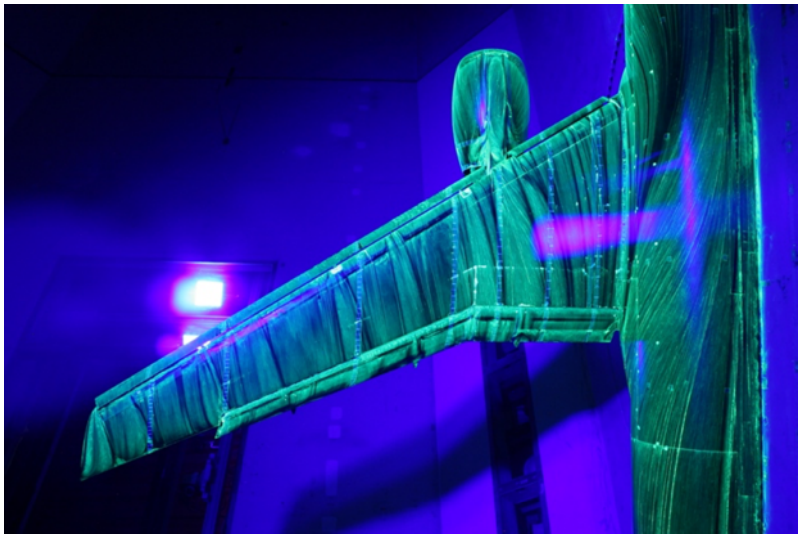


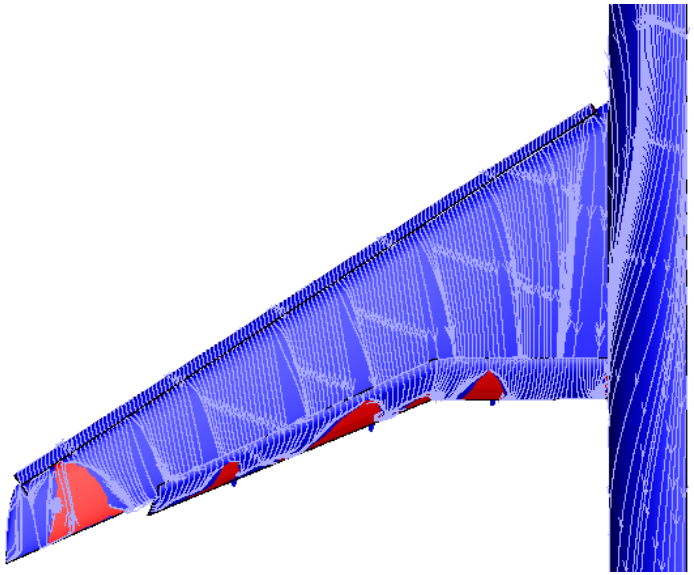


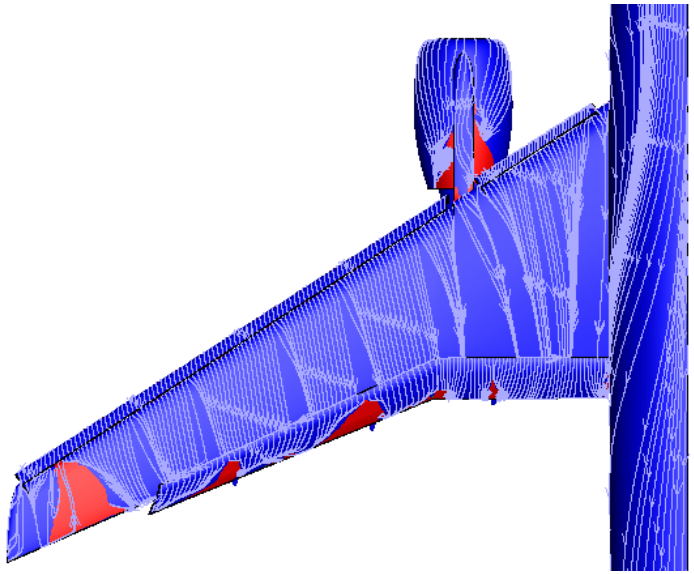


JSM results – C2 – PyNaOn x PyNaOff – 10.47°

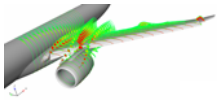


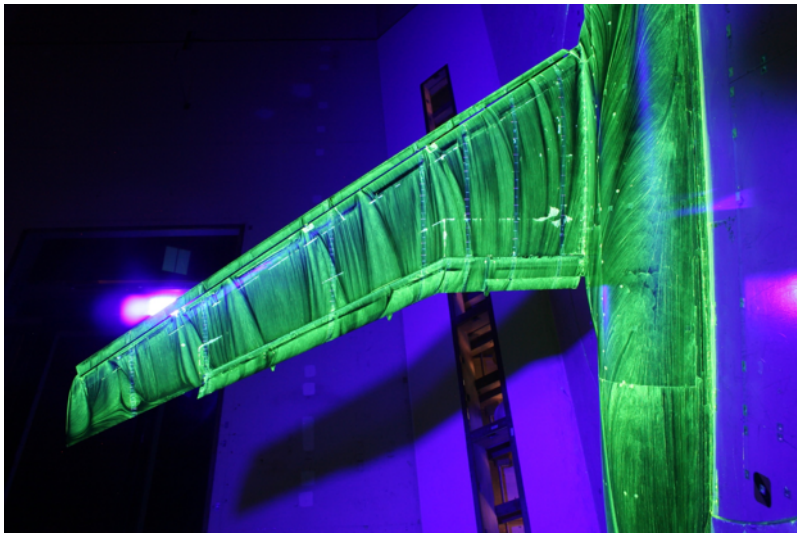


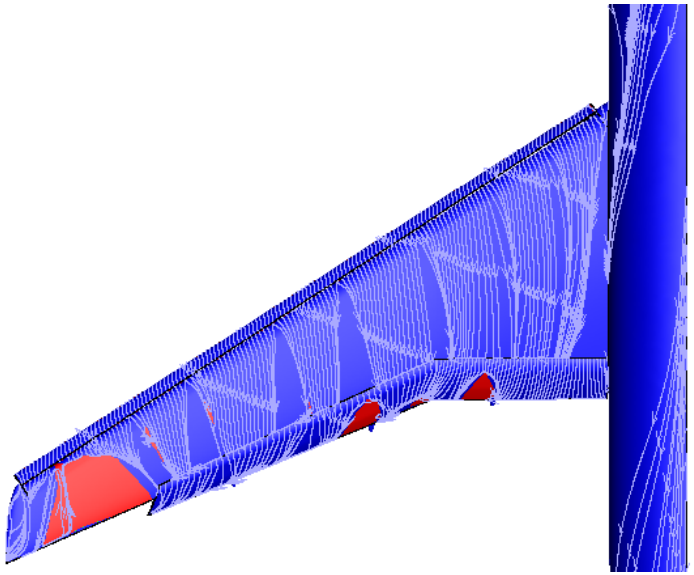


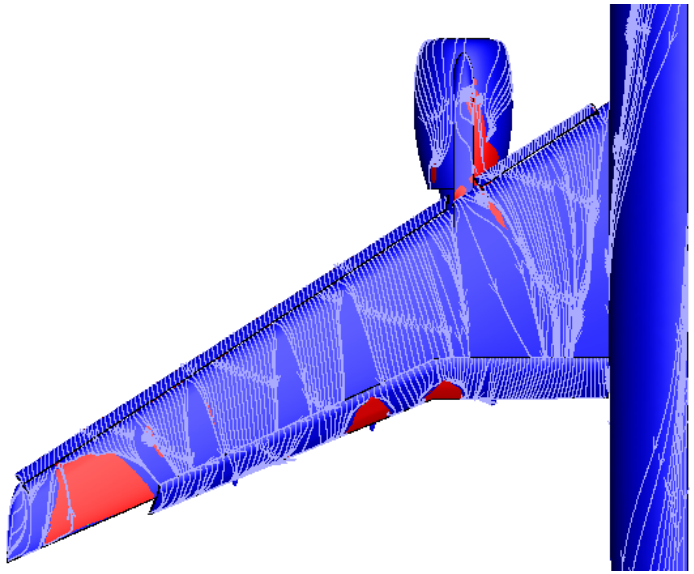


JSM results – C2 – PyNaOn x PyNaOff – 18.58°

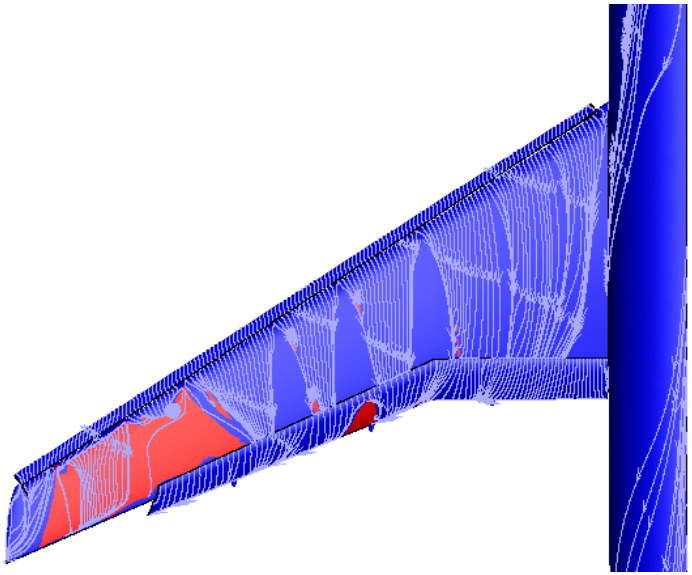


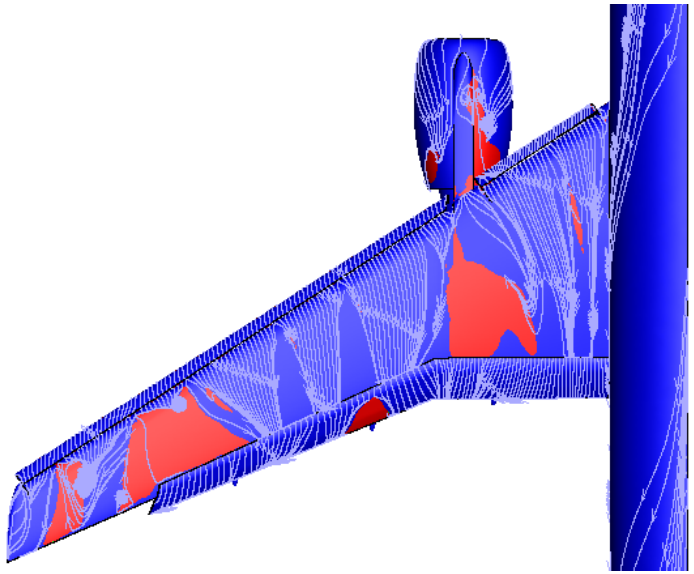




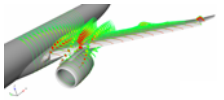


JSM results – C2 – PyNaOn x PyNaOff – 21.57°





JSM results –PyNaOff – 4.36°



INBOARD SECTIONS

OUTBOARD SECTIONS

SLAT WING FLAP SLAT WING FLAP

A-A

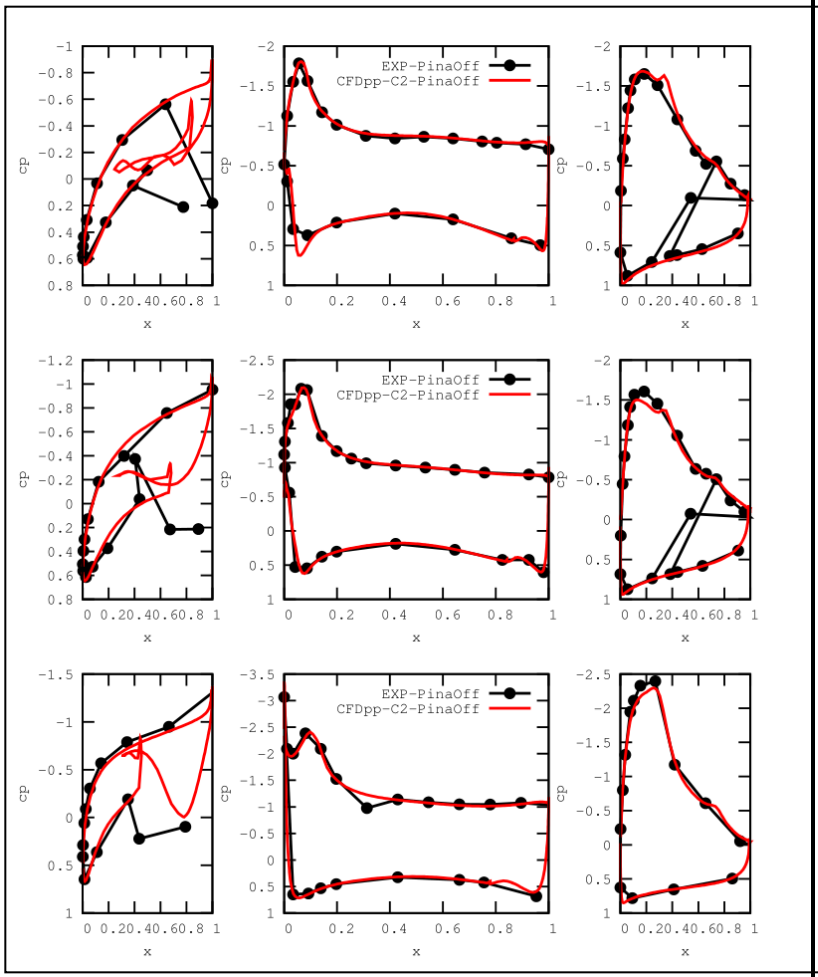
B-B

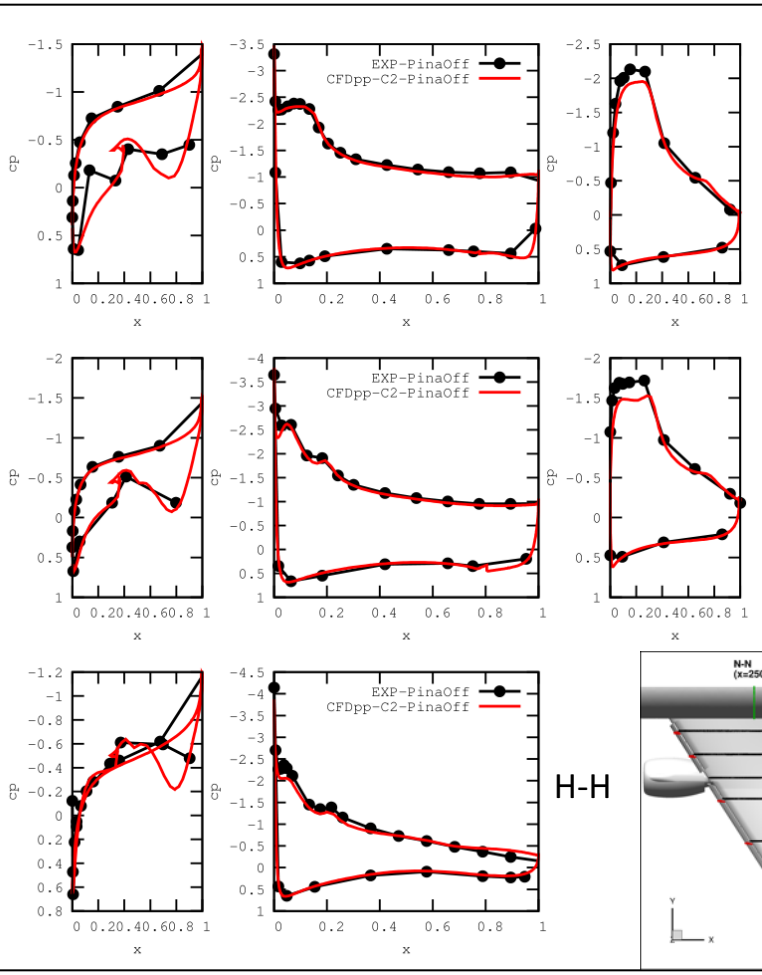
D-D

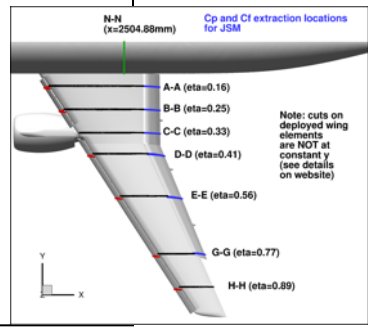
E-E

G-G

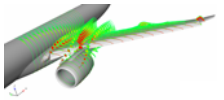
H-H





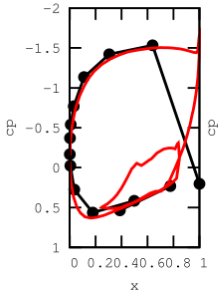
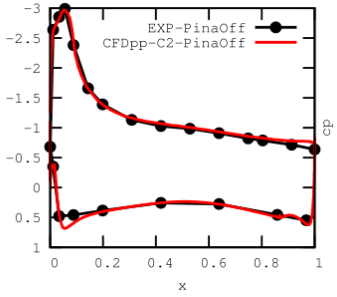
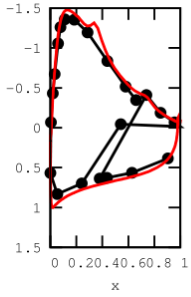
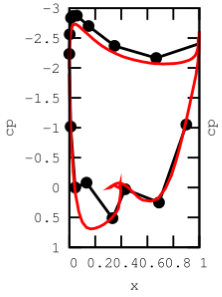
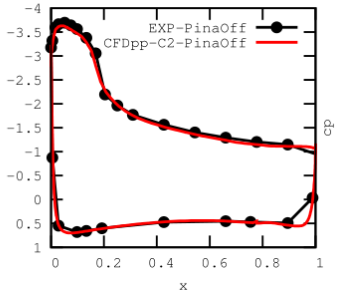
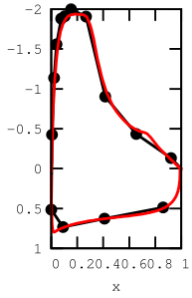
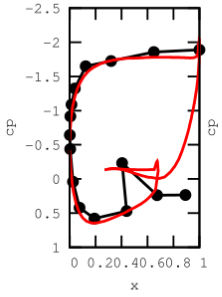
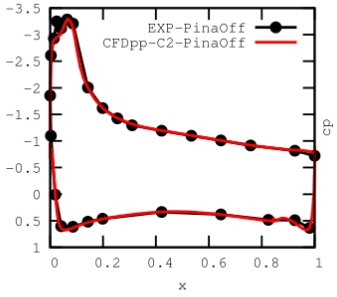
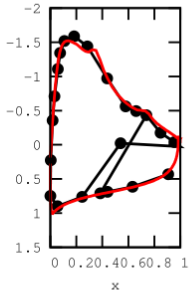
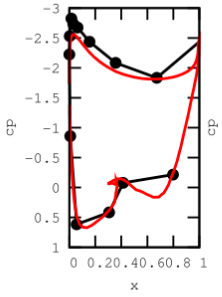
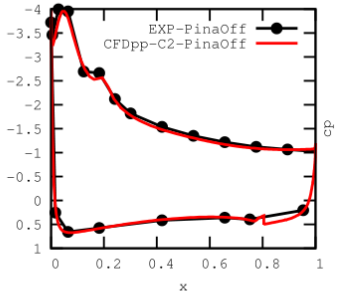
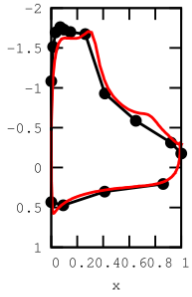
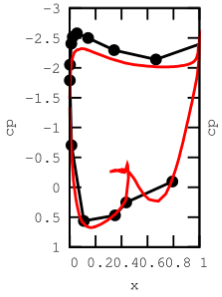
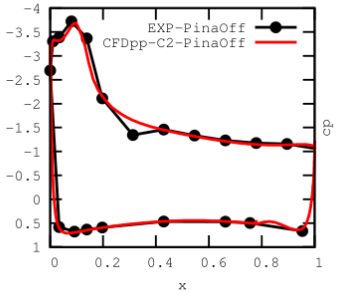
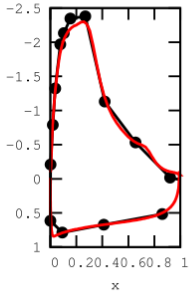
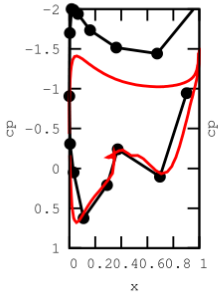
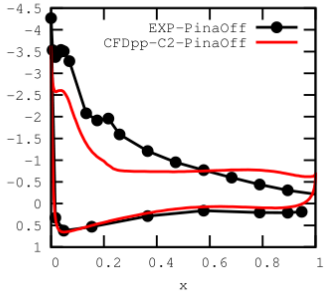


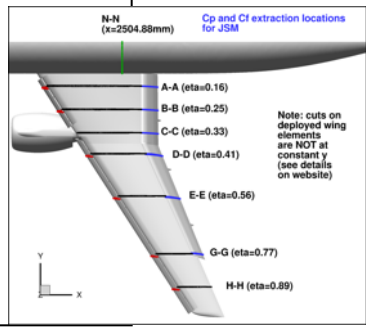
JSM results –PyNaOff – 10.47°



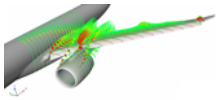
INBOARD SECTIONS

OUTBOARD SECTIONS

	SLAT	WING	FLAP		SLAT	WING	FLAP	
A-A				E-E				
B-B				G-G				
D-D				H-H				



JSM results –PyNaOff – 18.58°



INBOARD SECTIONS

OUTBOARD SECTIONS

SLAT WING FLAP SLAT WING FLAP

A-A

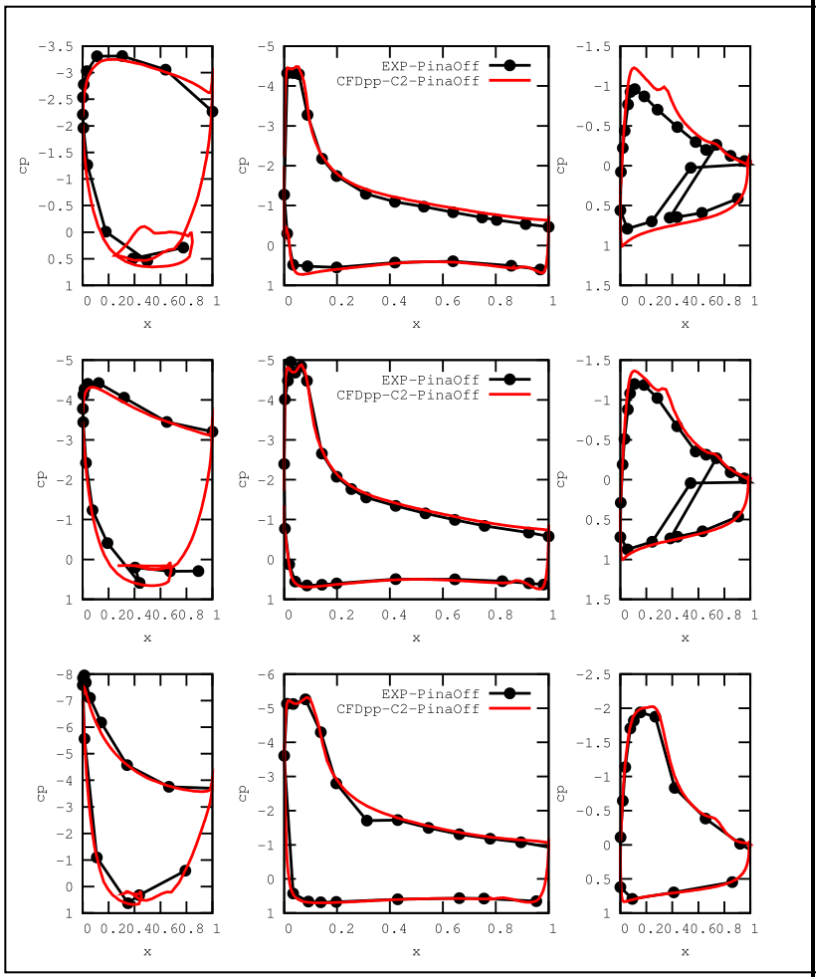
B-B

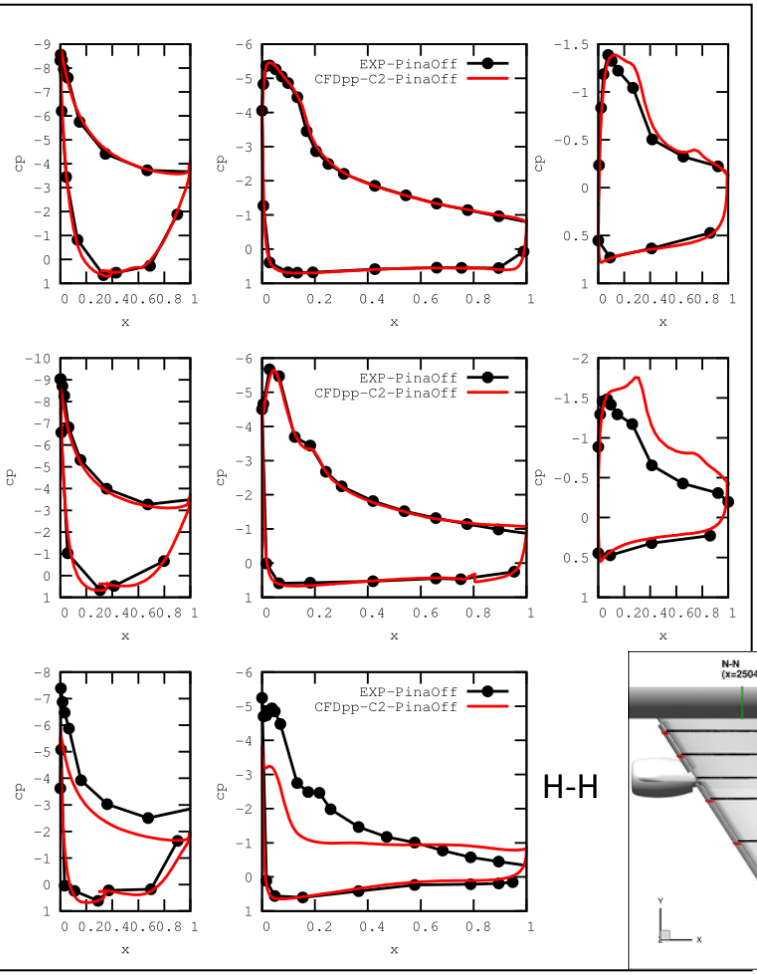
D-D

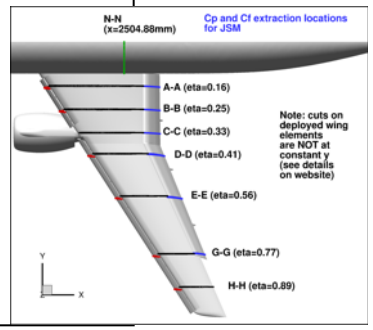
E-E

G-G

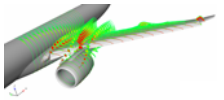
H-H







JSM results –PyNaOff – 21.57°



INBOARD SECTIONS

OUTBOARD SECTIONS

SLAT WING FLAP SLAT WING FLAP

A-A

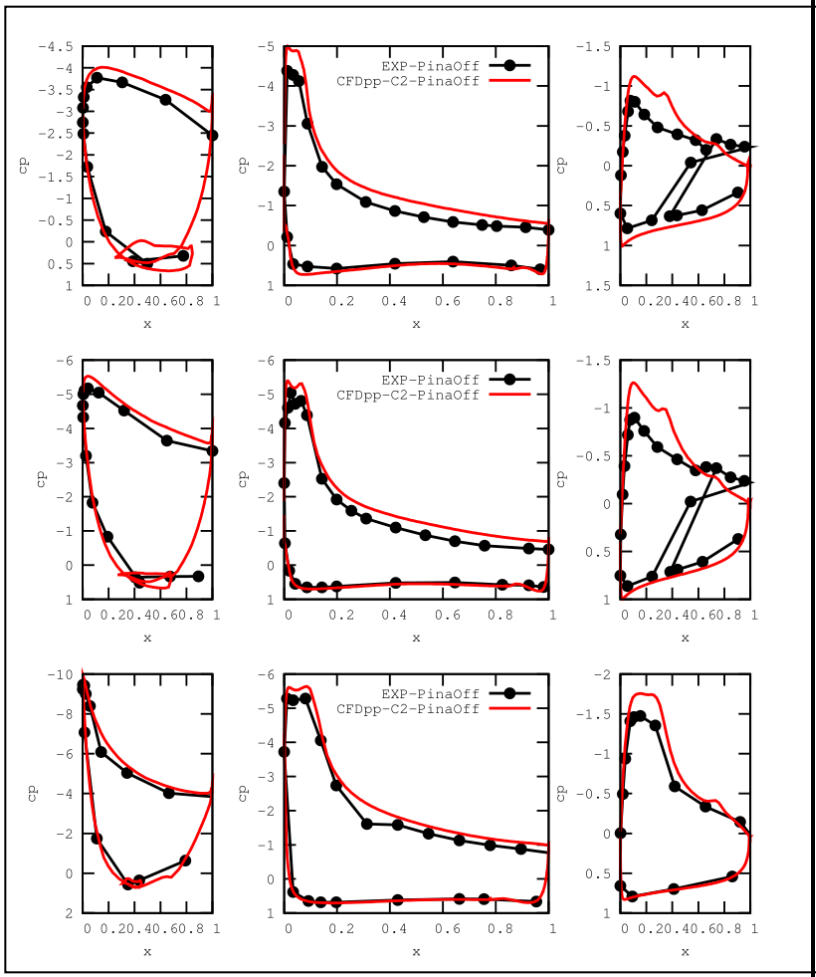
B-B

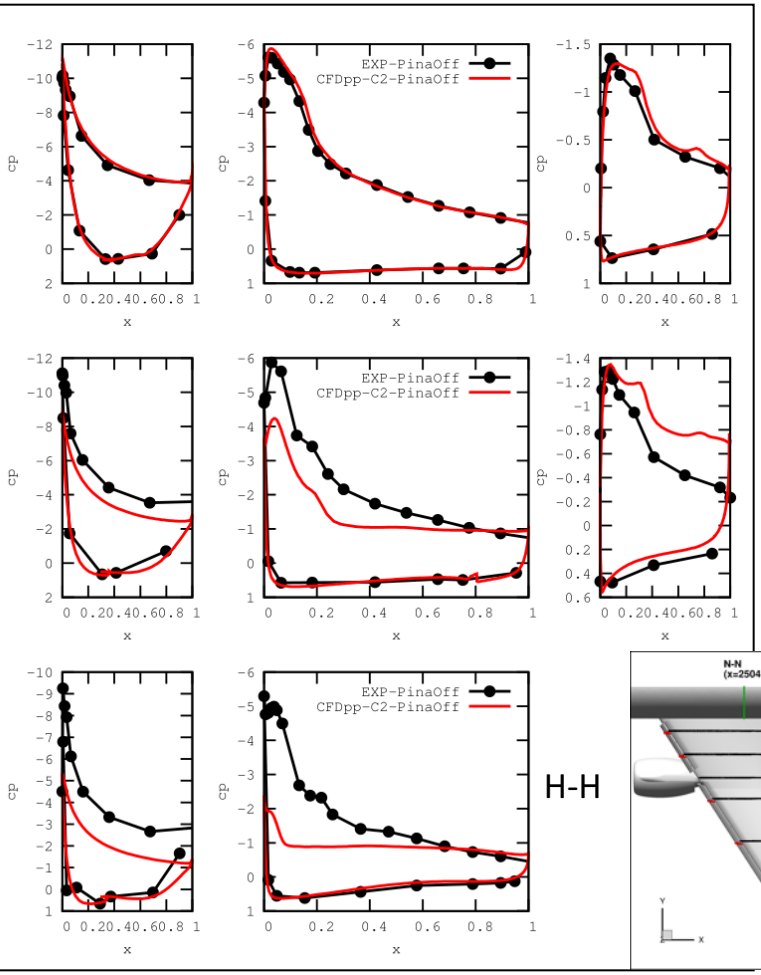
D-D

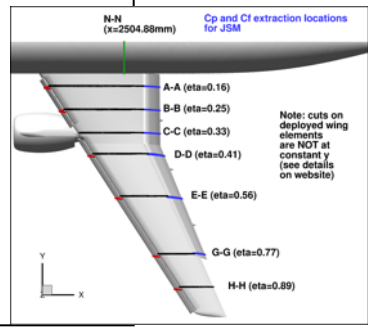
E-E

G-G

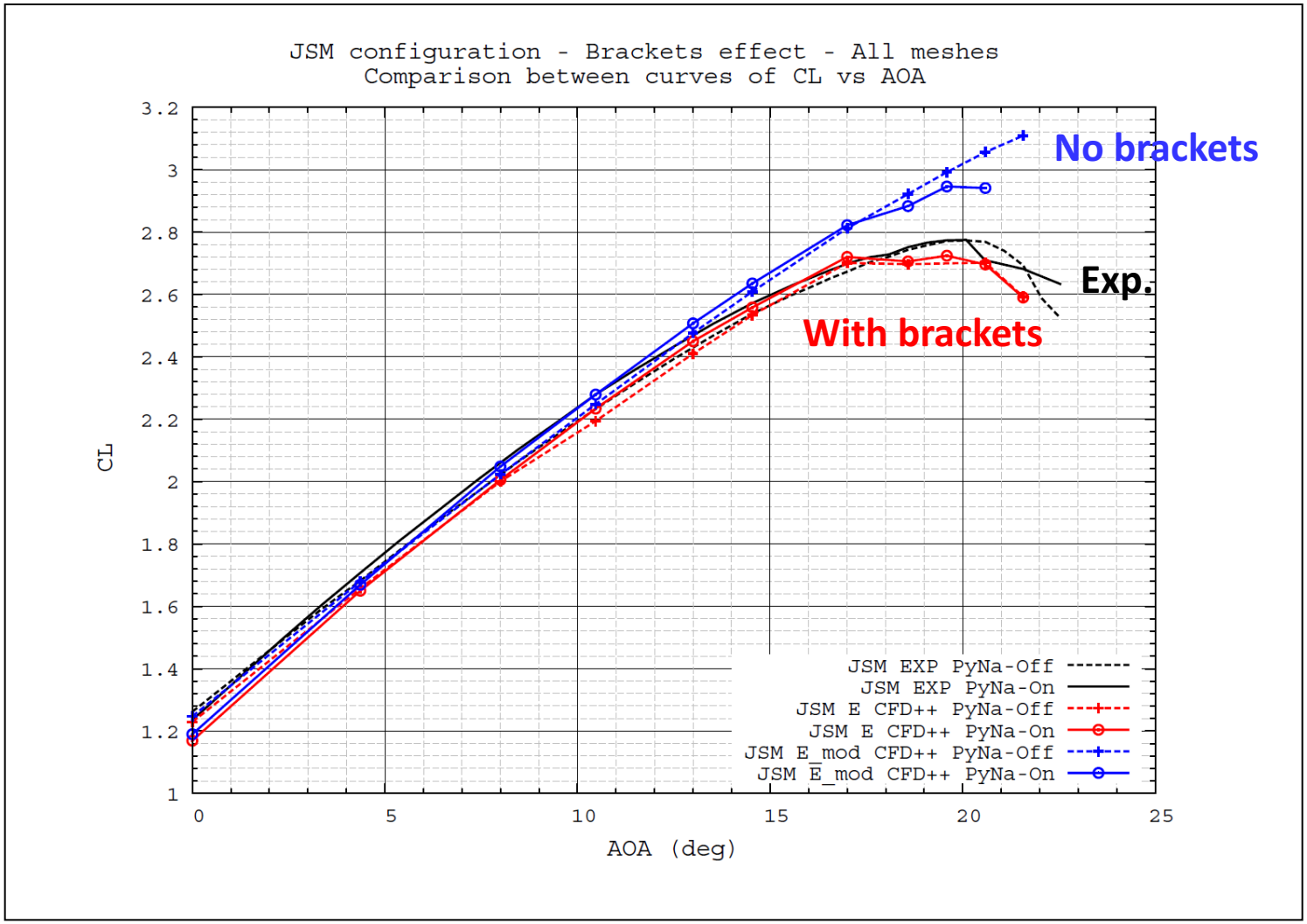
H-H



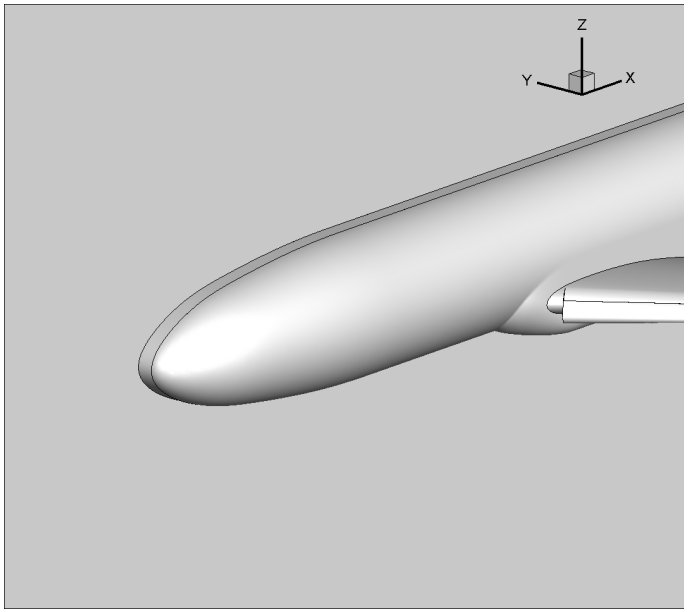


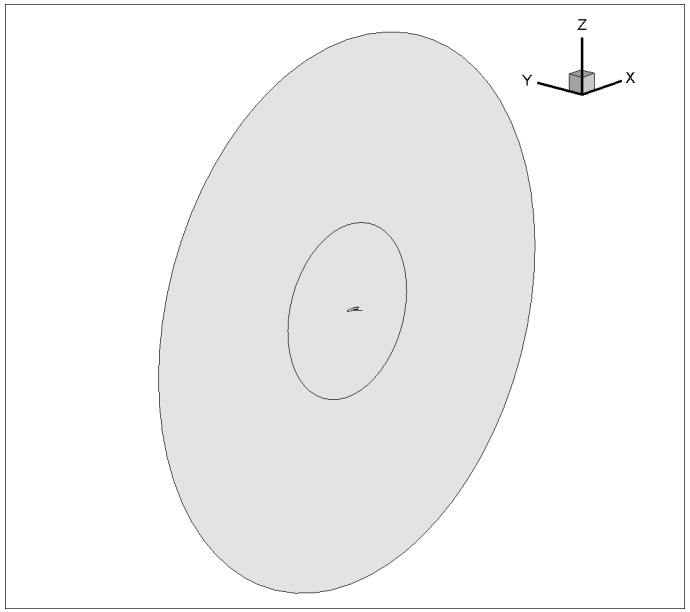


JSM results – Slat brackets effect



JSM results – Standoff and viscous tunnel wall effect

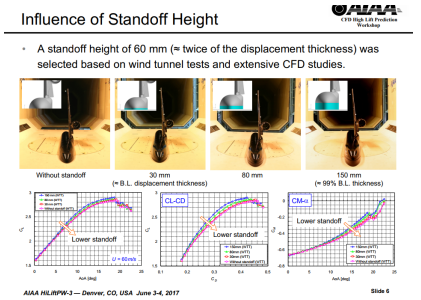




60 mm standoff (~ twice the BL displacement thickness)

But: $\delta_{99\%} \sim 8 \times \delta^*$

Viscous wall radius: 24 meters (yields a 30 mm BL displacement thickness at the fuselage nose)


Influence of Standoff Height

- A standoff height of 60 mm (≈ twice of the displacement thickness) was selected based on wind tunnel tests and extensive CFD studies.

Without standoff | 30 mm (≈ B.L. displacement thickness) | 80 mm | 150 mm (≈ 99% B.L. thickness)

Lower standoff | CL-CD | Lower standoff | CM-α | Lower standoff

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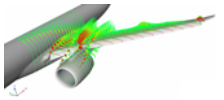
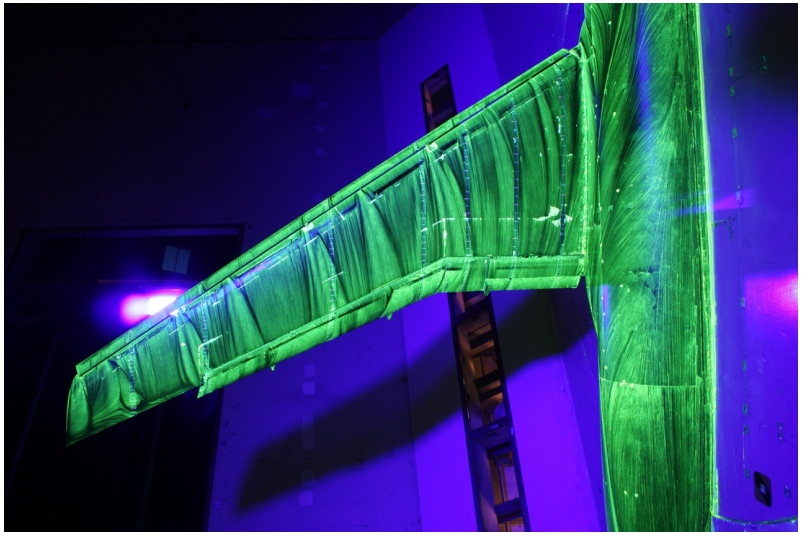
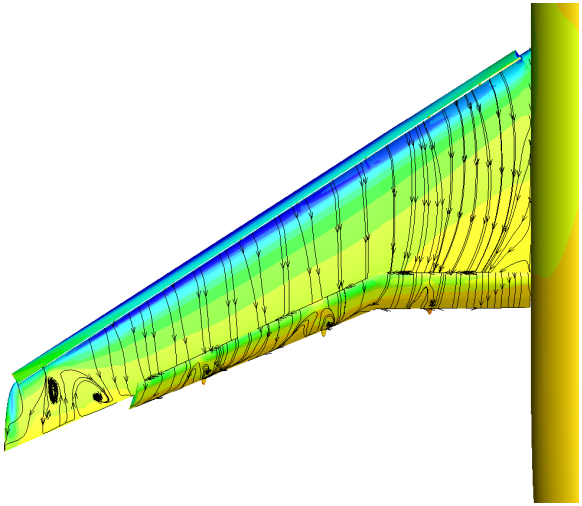
JSM results – Standoff and viscous tunnel wall effect

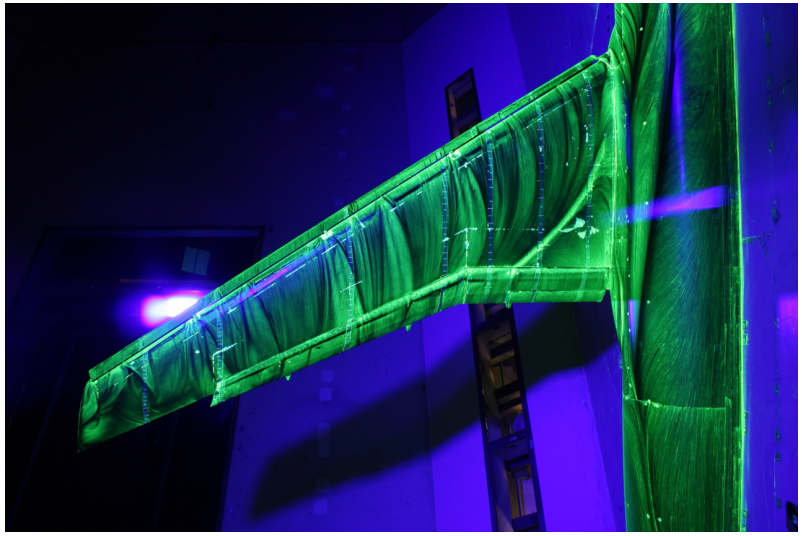


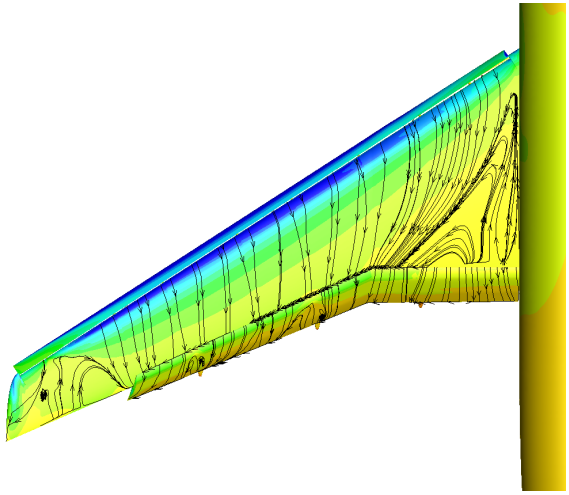
18.58 °



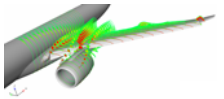


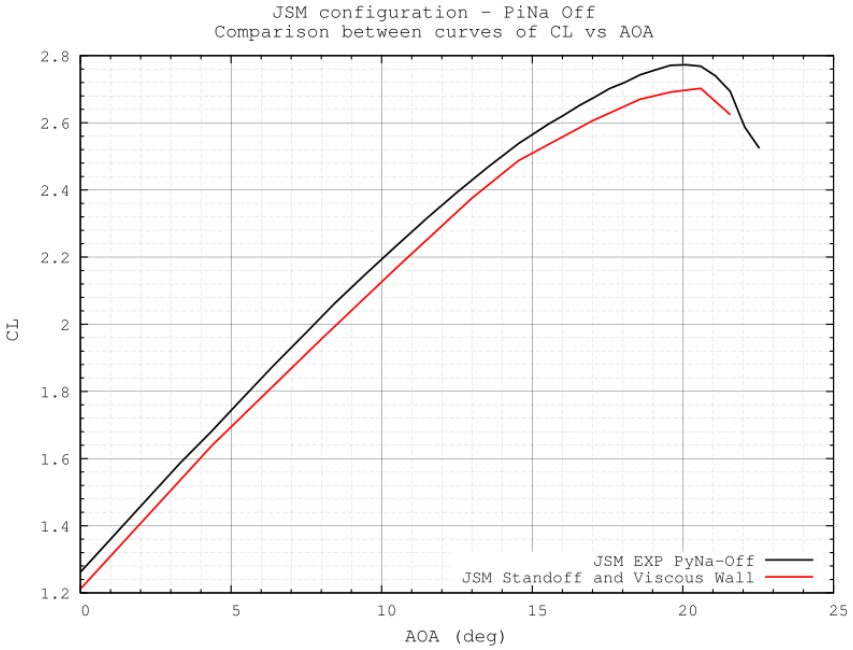
21.57 °

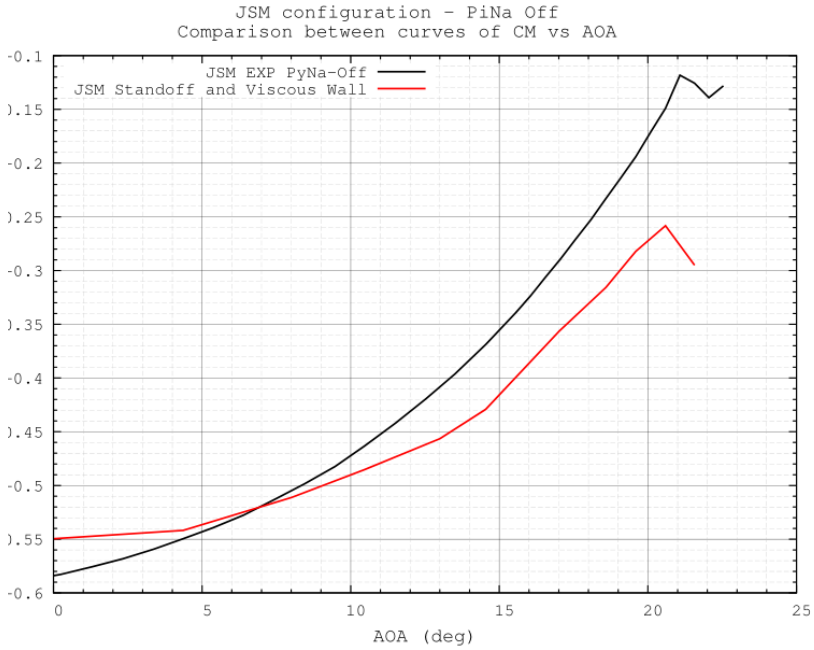




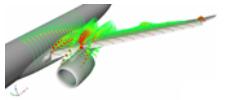
JSM results – Standoff and viscous tunnel wall effect





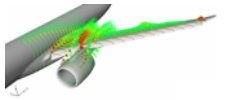


Brief overview of JSM results

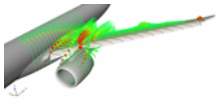


- Coefficients & surface streamlines
  - Both grids employed, C2 and E, yielded good results for DCL, DCD and DCM up to stall
    - Outlier in results for grid E
  - CL/CD ratio did not compare well to experiment
  - Behavior of CL near stall could be improved
    - Stall starts on the inboard panel for experiment while CFD predicts stall starting on the outboard panel
      - Slat brackets effect seems a little exaggerated at high AOA
      - However, results without slat brackets were not representative of experiment
      - Preliminary results show that standoff and tunnel wall BL might influence the results

Concluding remarks

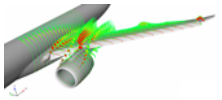


- Although a lot of improvements have happened in the past, high-lift flow prediction is still difficult
- Processing capabilities and enhancements in mesh generation allowed an increase in geometry fidelity, such as including slat and flap brackets as well as wind tunnel walls
    - Where to refine, how much to refine, still are unanswered questions
- Clear challenge remain in the accurate prediction of flow separation in terms of position and extent
    - Flow physics (transition, wind tunnel effects, unsteady vs steady etc.)
    - Turbulence modeling



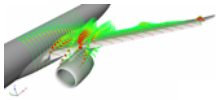
THANK YOU!

QUESTIONS?

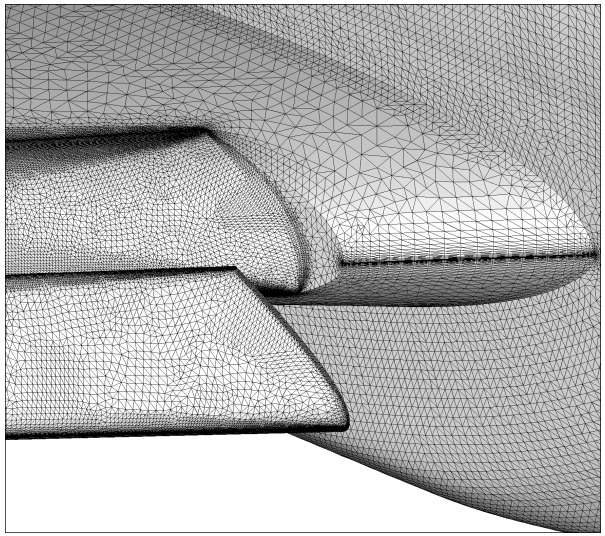


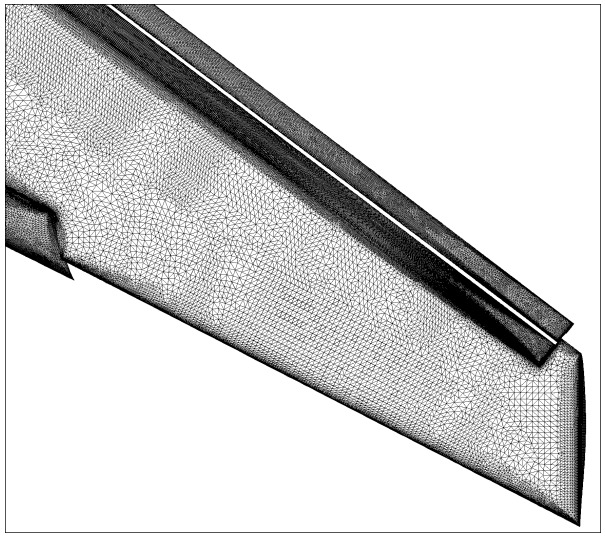
CRM – APPENDIX

Grid comparison: B2, B3, M5

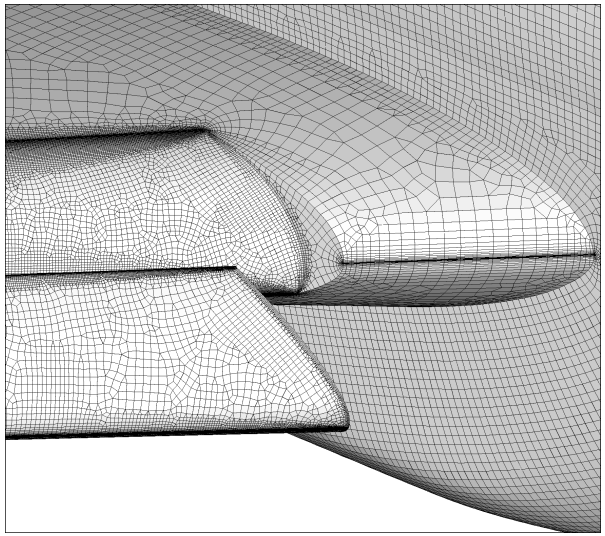


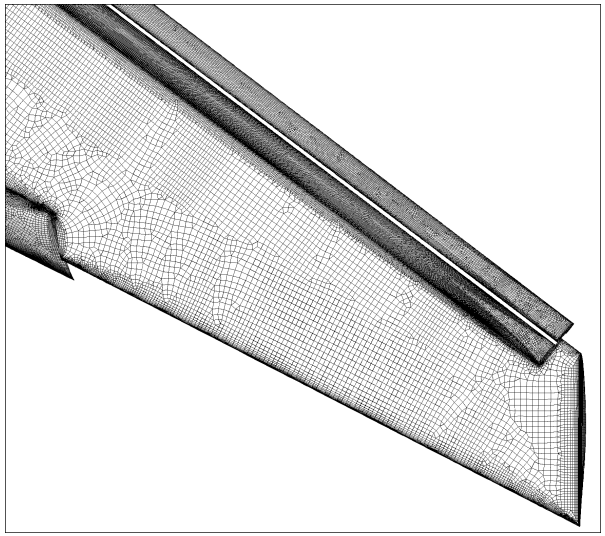
B2 (fine)



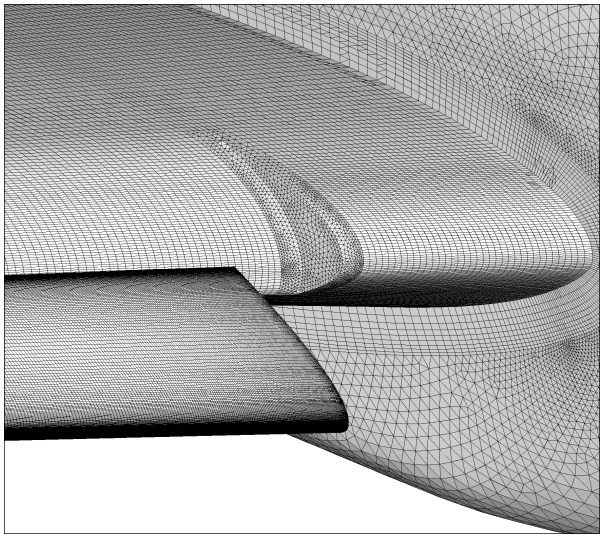


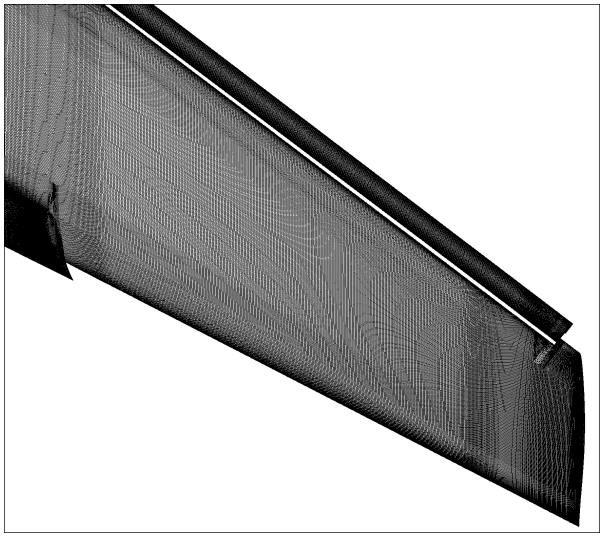
B3 (fine)





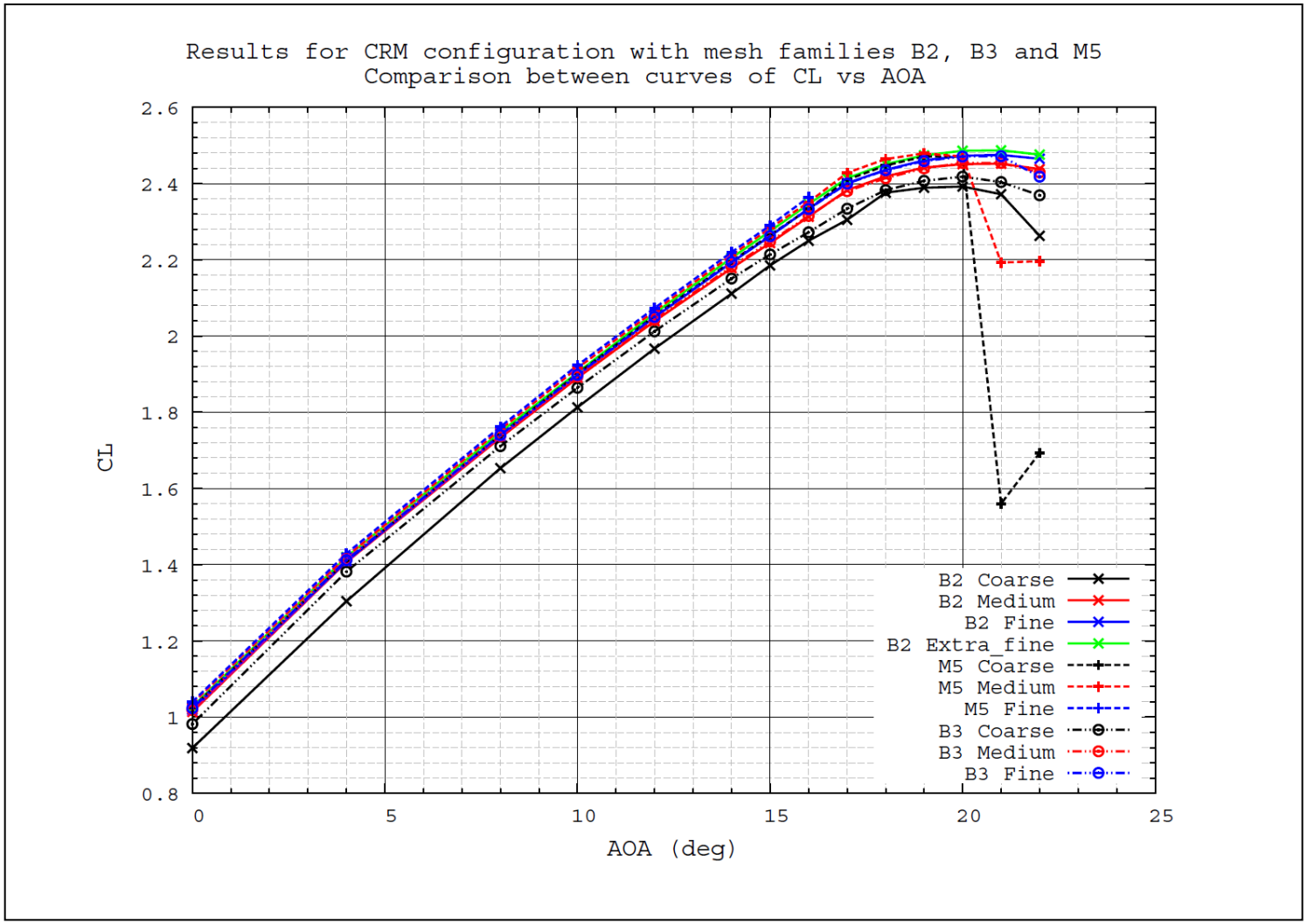
M5 (Medium)





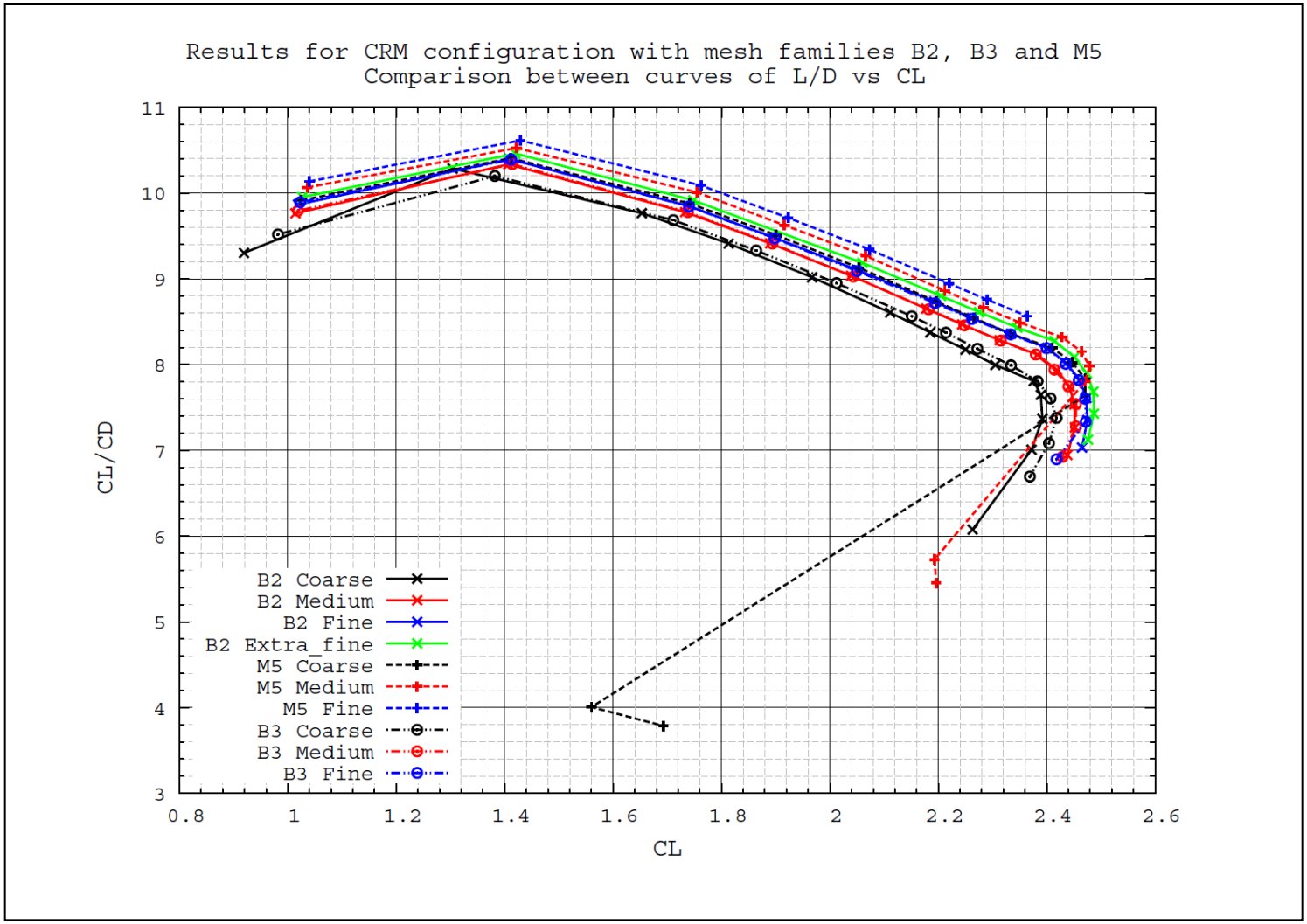
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5



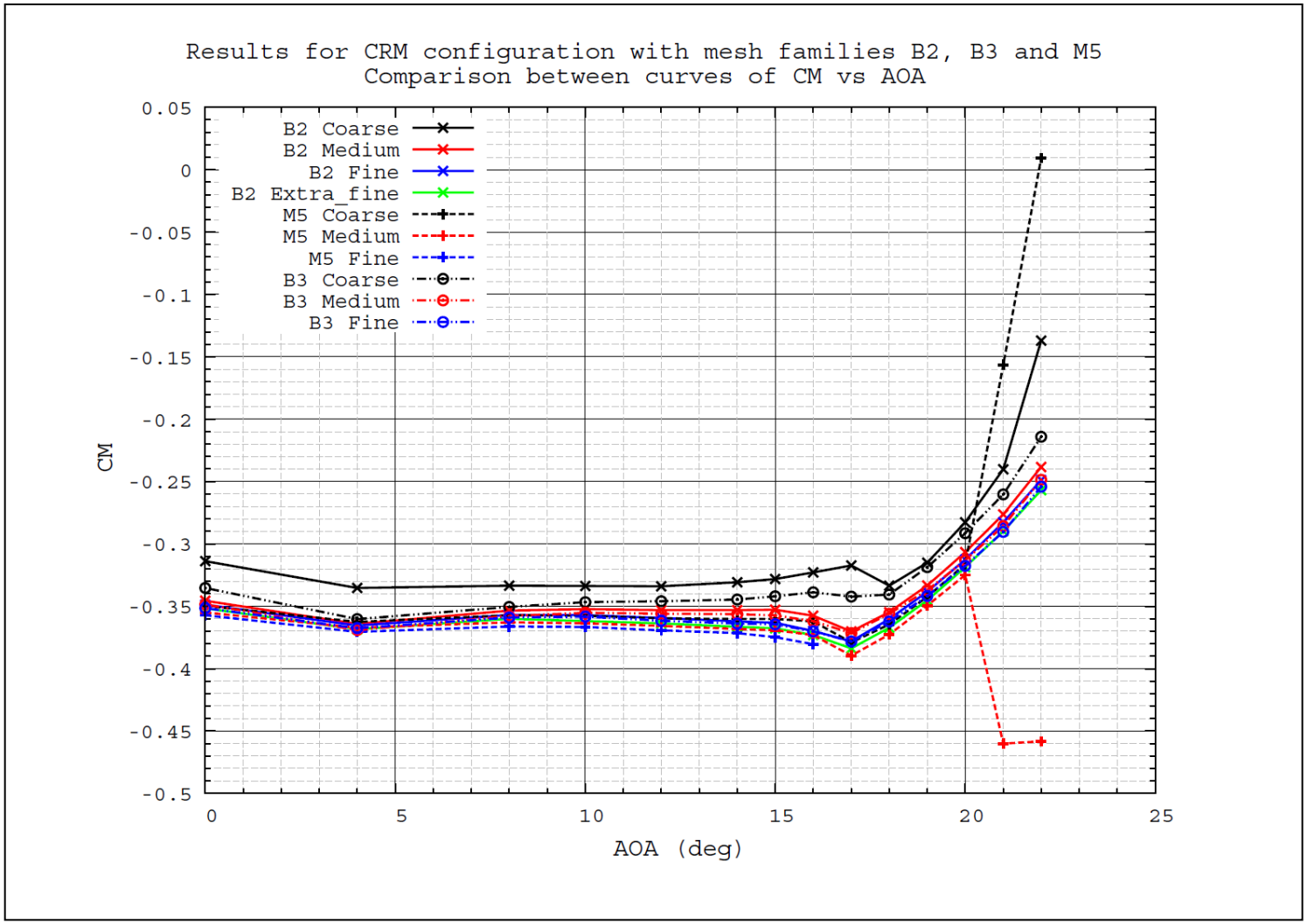
HL-CRM results – coefficients – CFD++

Grids B2, B3, M5



HL-CRM results – coefficients – CFD++

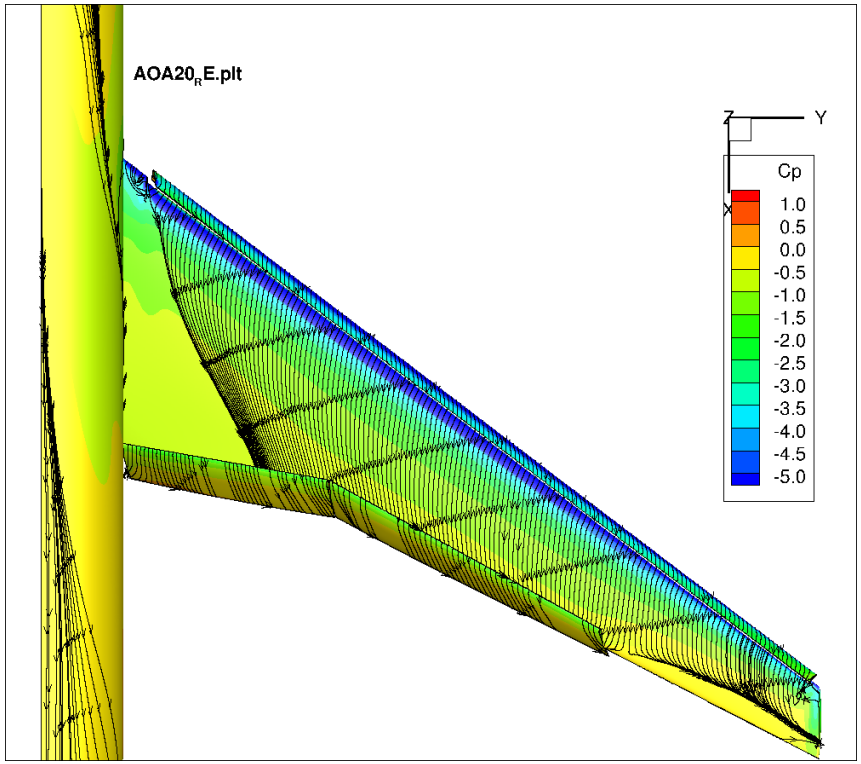
Grids B2, B3, M5



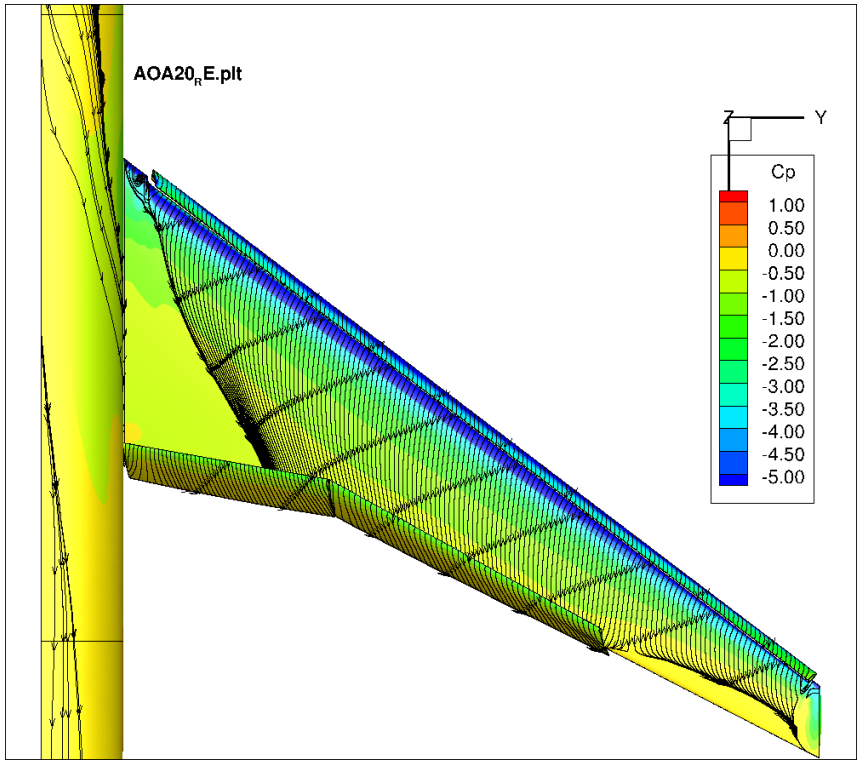
HL-CRM results – 20° – CFD++

Grids B2 fine x M5 medium

B2

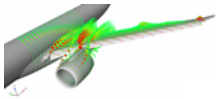


M5

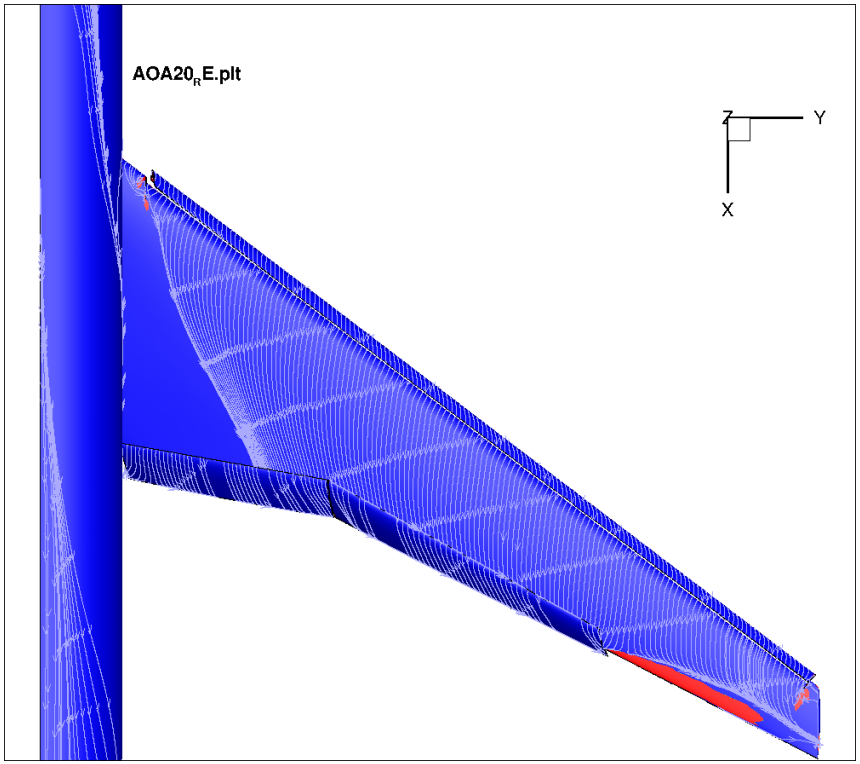


HL-CRM results – 20° – CFD++

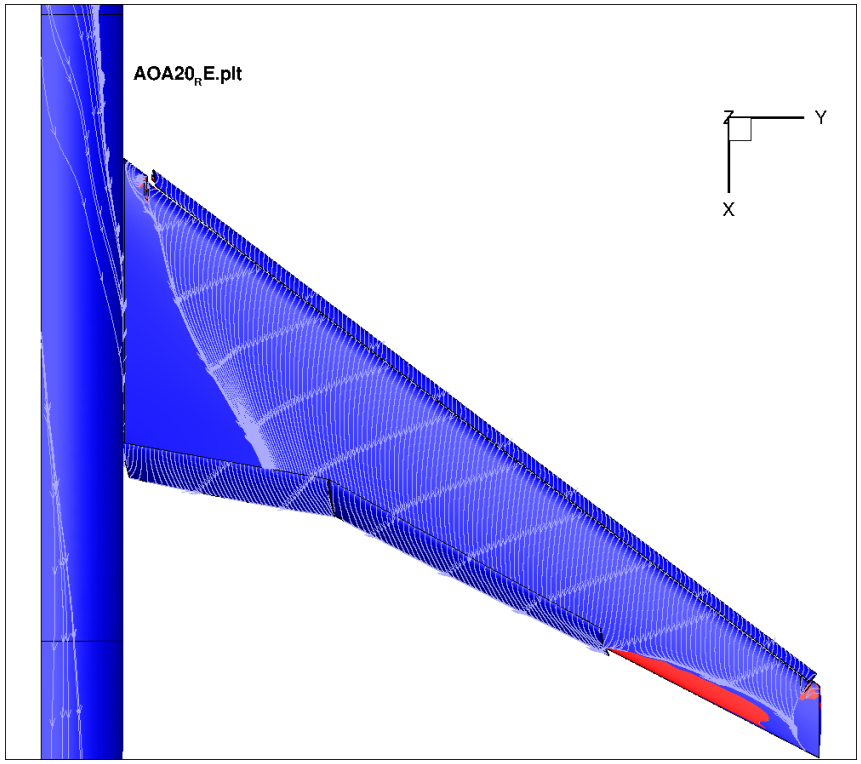
Grids B2 fine x M5 medium



B2



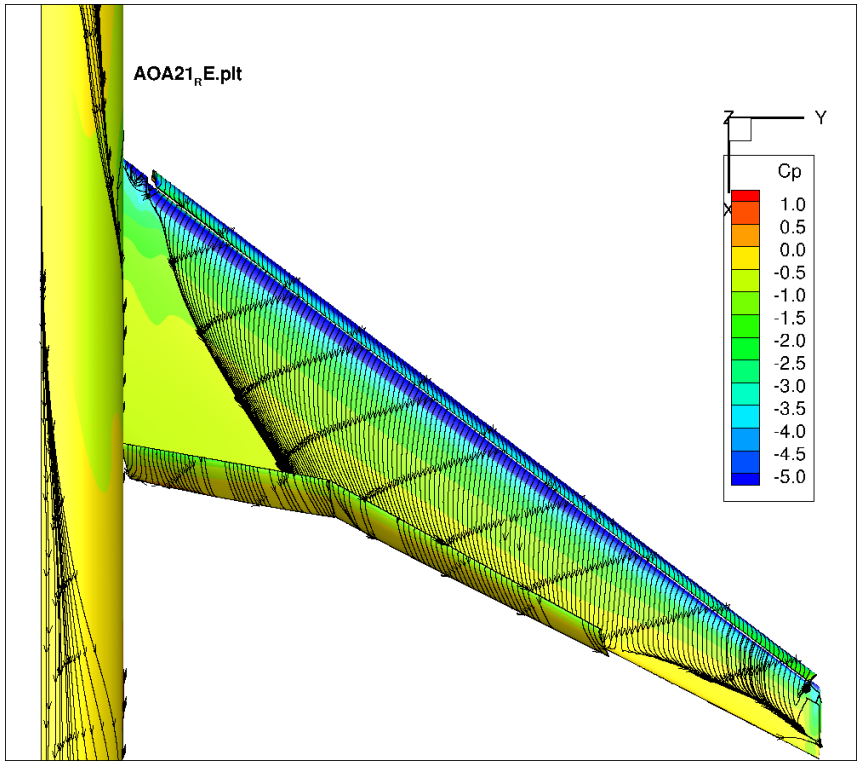
M5



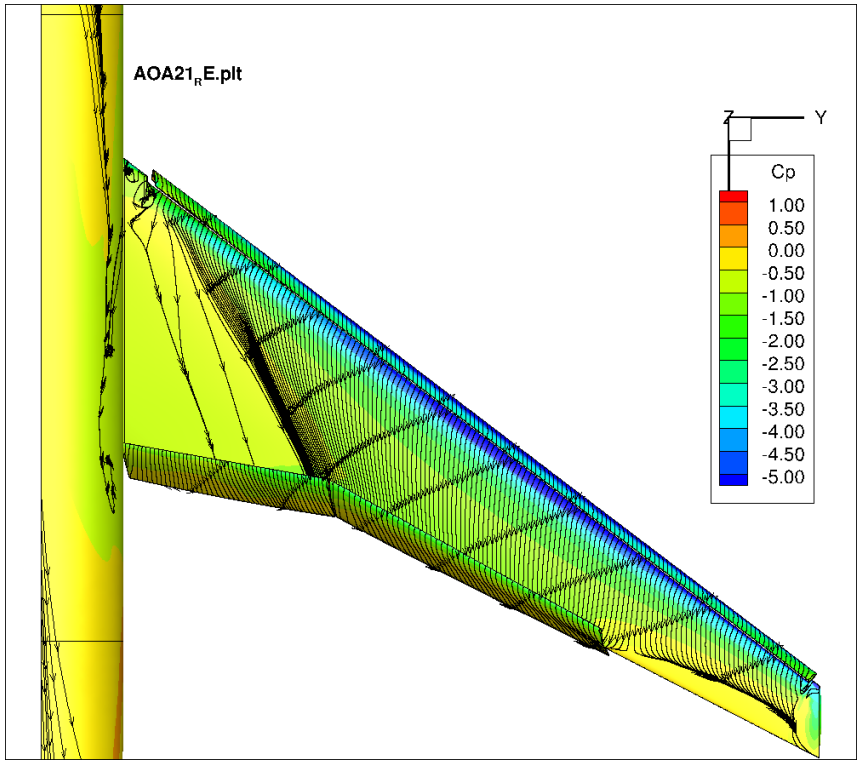
HL-CRM results – 21° – CFD++

Grids B2 fine x M5 medium

B2



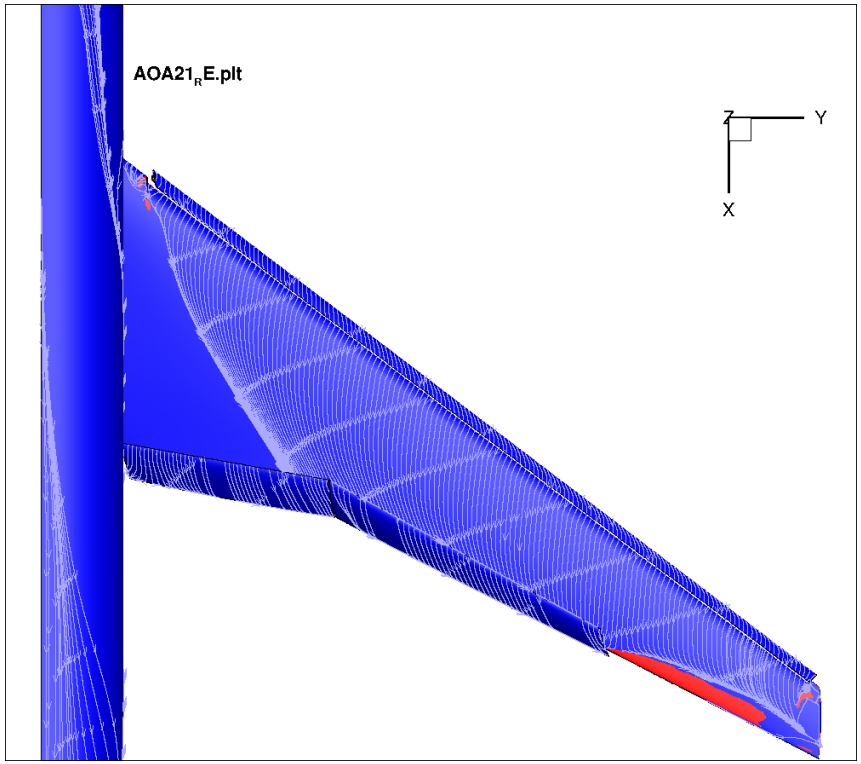
M5



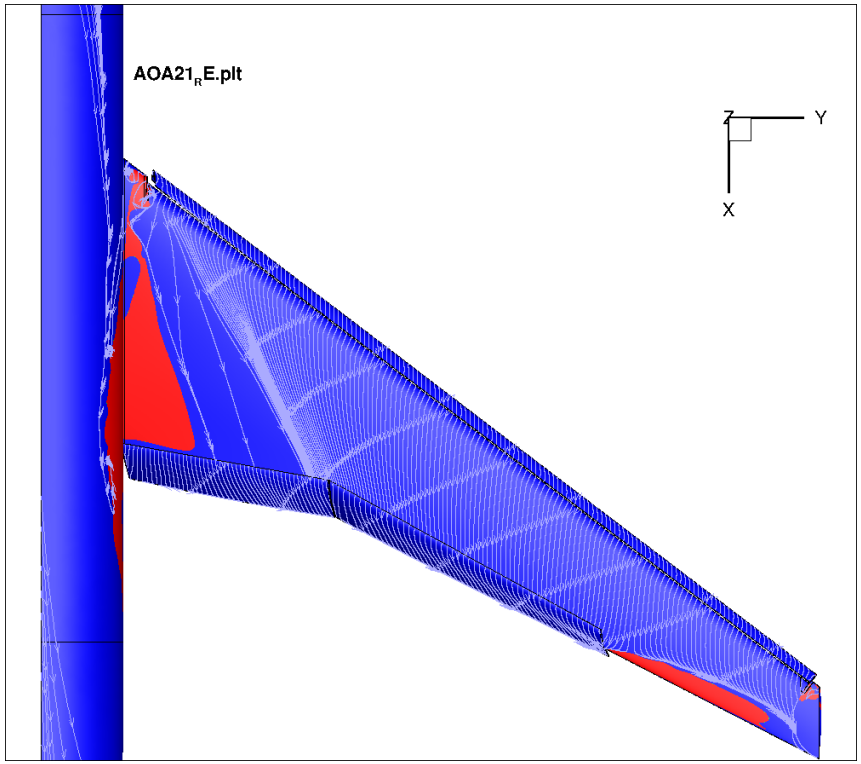
HL-CRM results – 21° – CFD++

Grids B2 fine x M5 medium

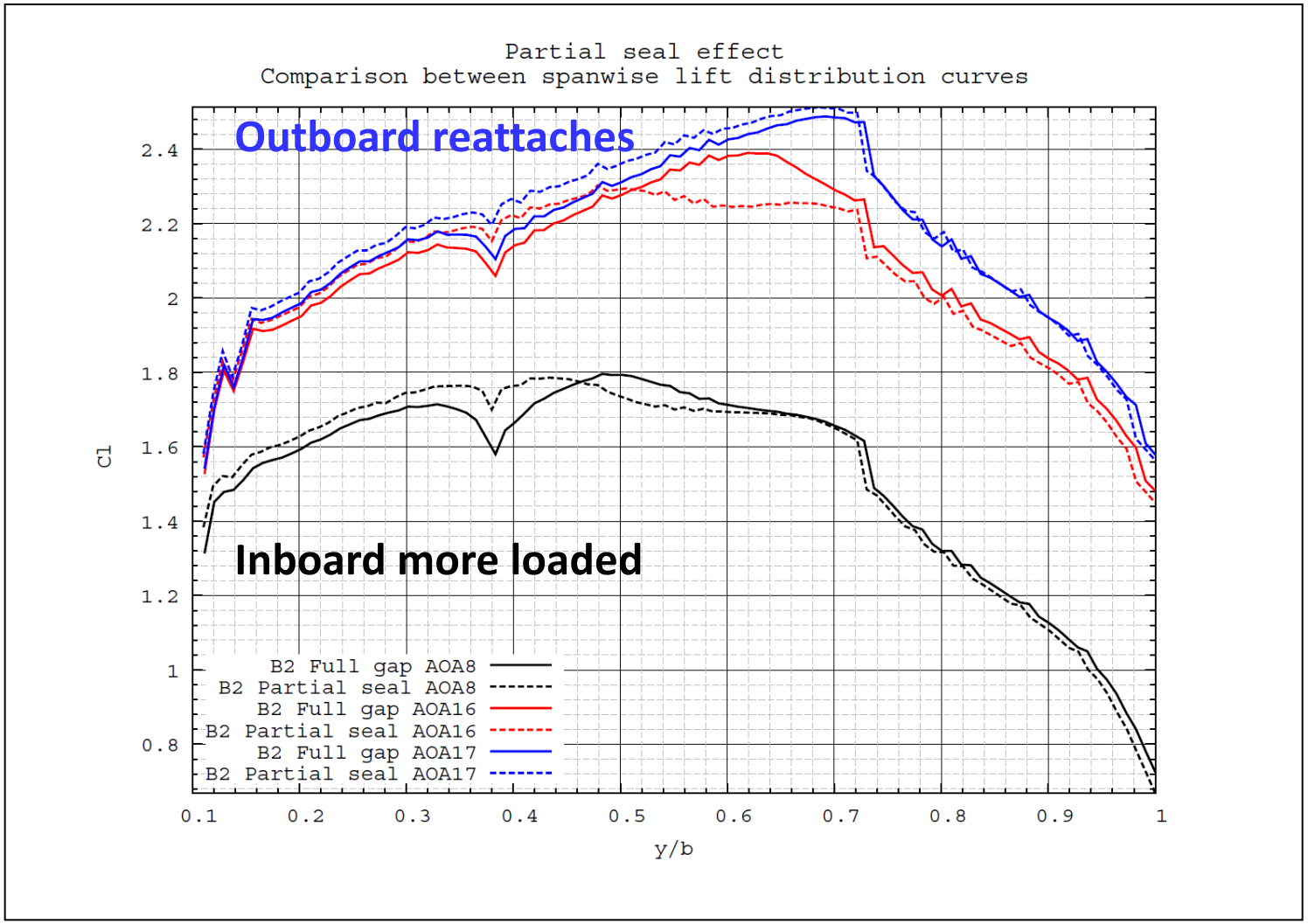
B2



M5

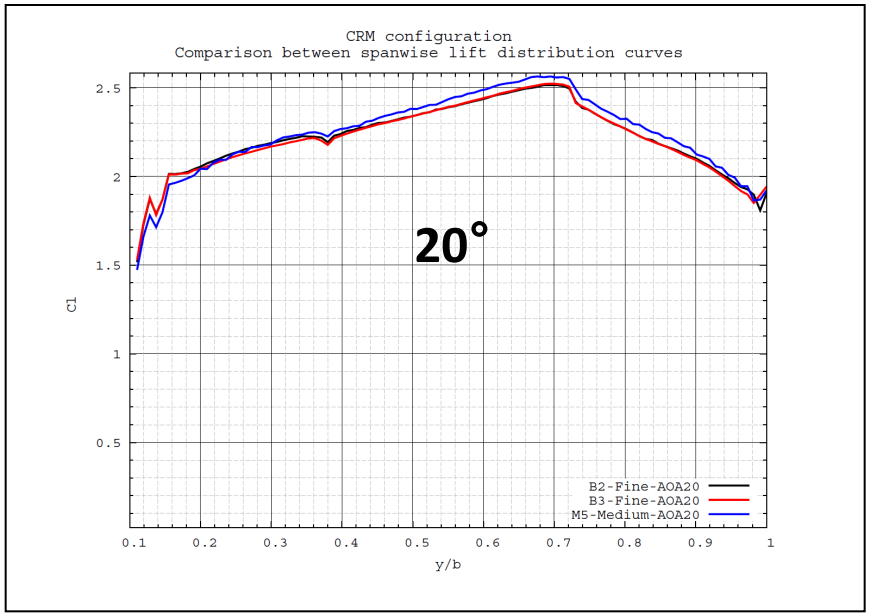


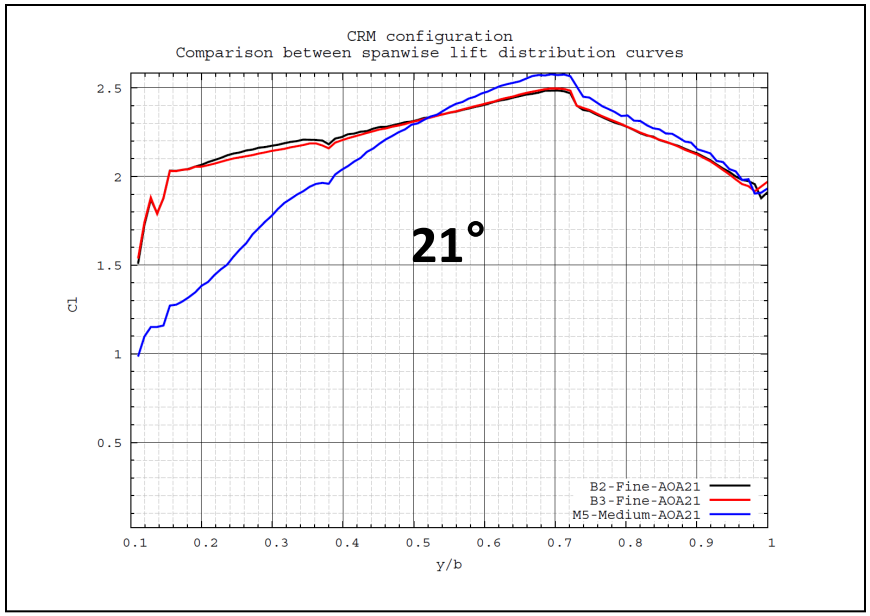
HL-CRM results – sealed gap x non-sealed – cl x span



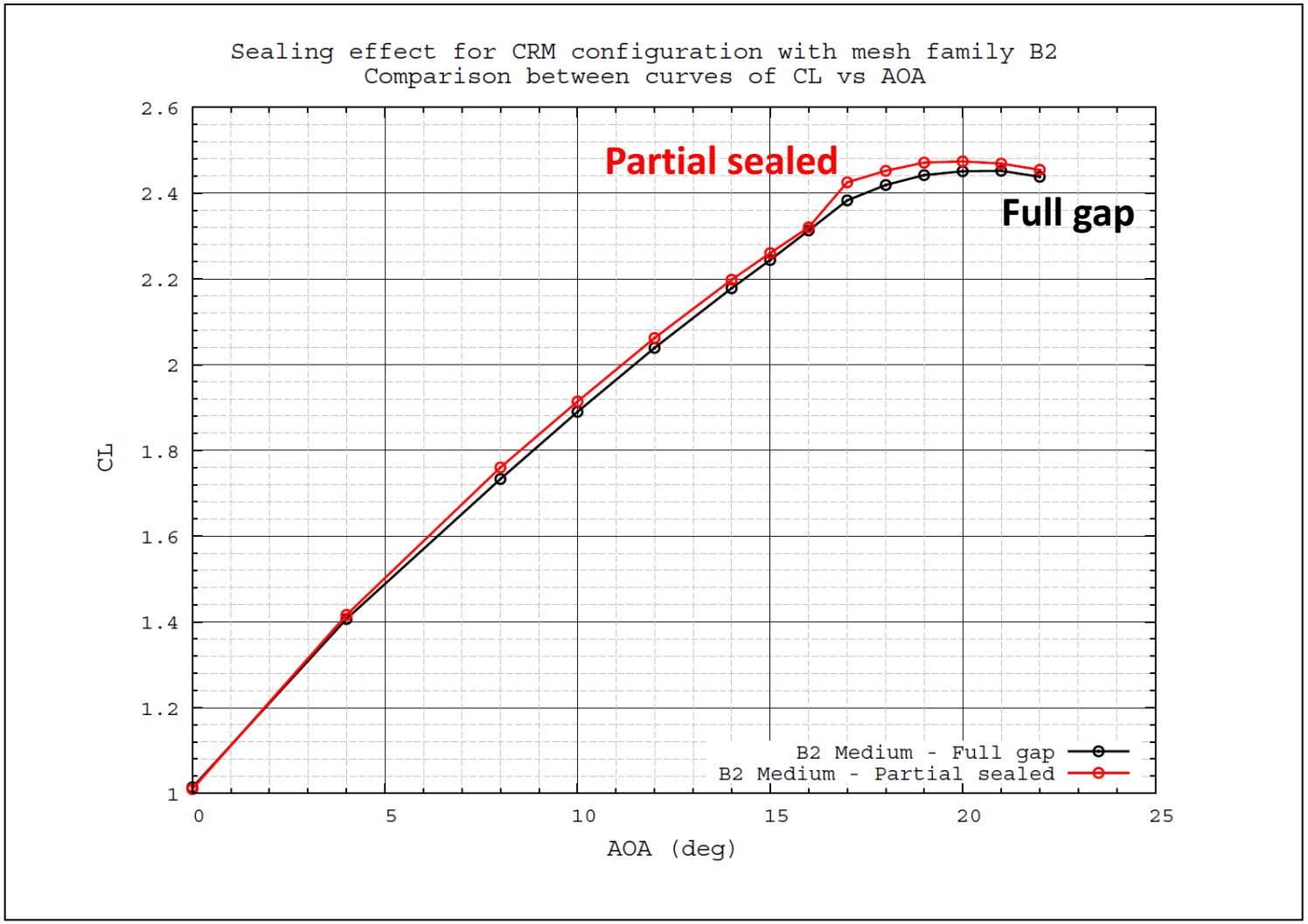
HL-CRM results – 21° – CFD++

Grids B2 fine x M5 medium

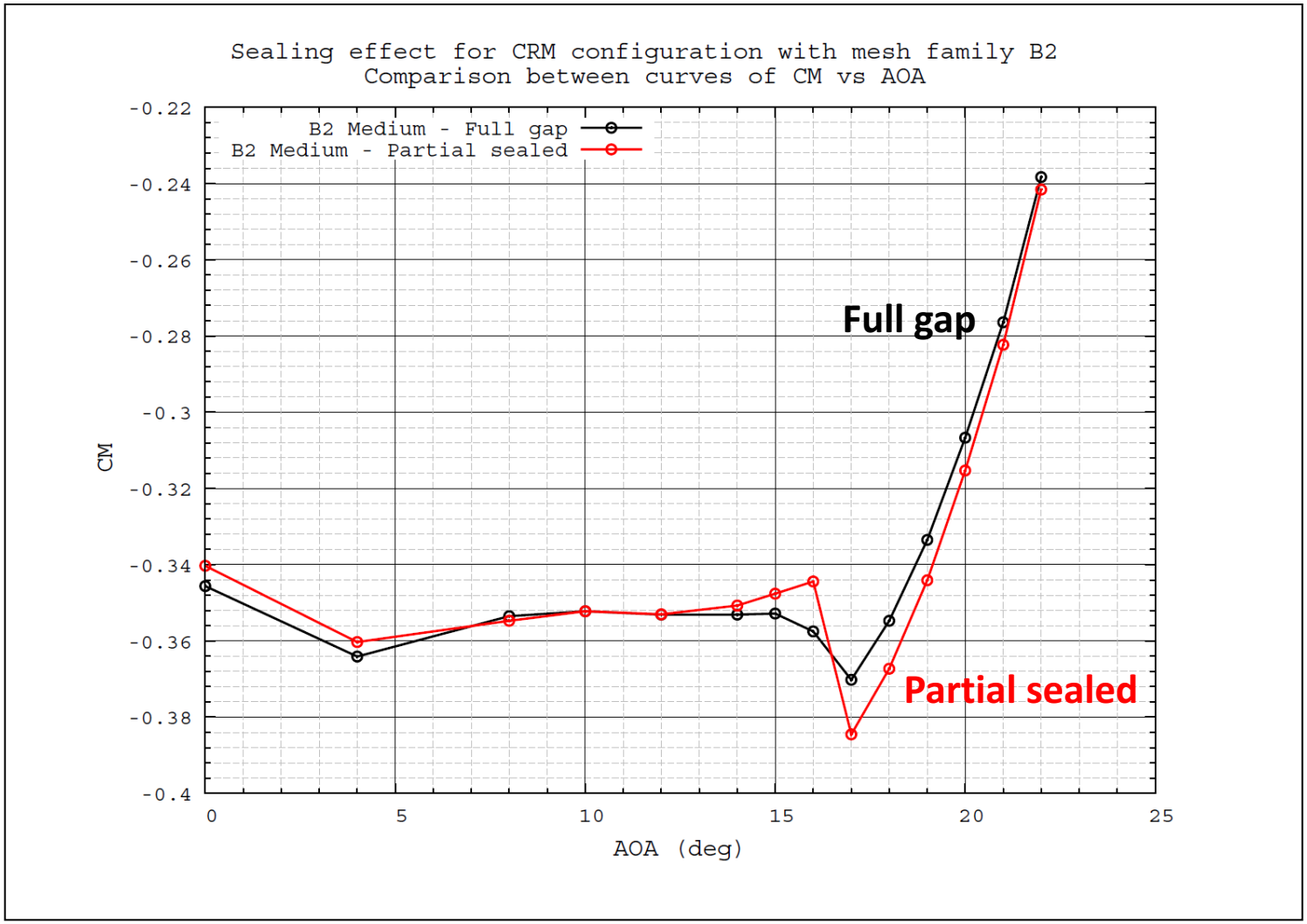




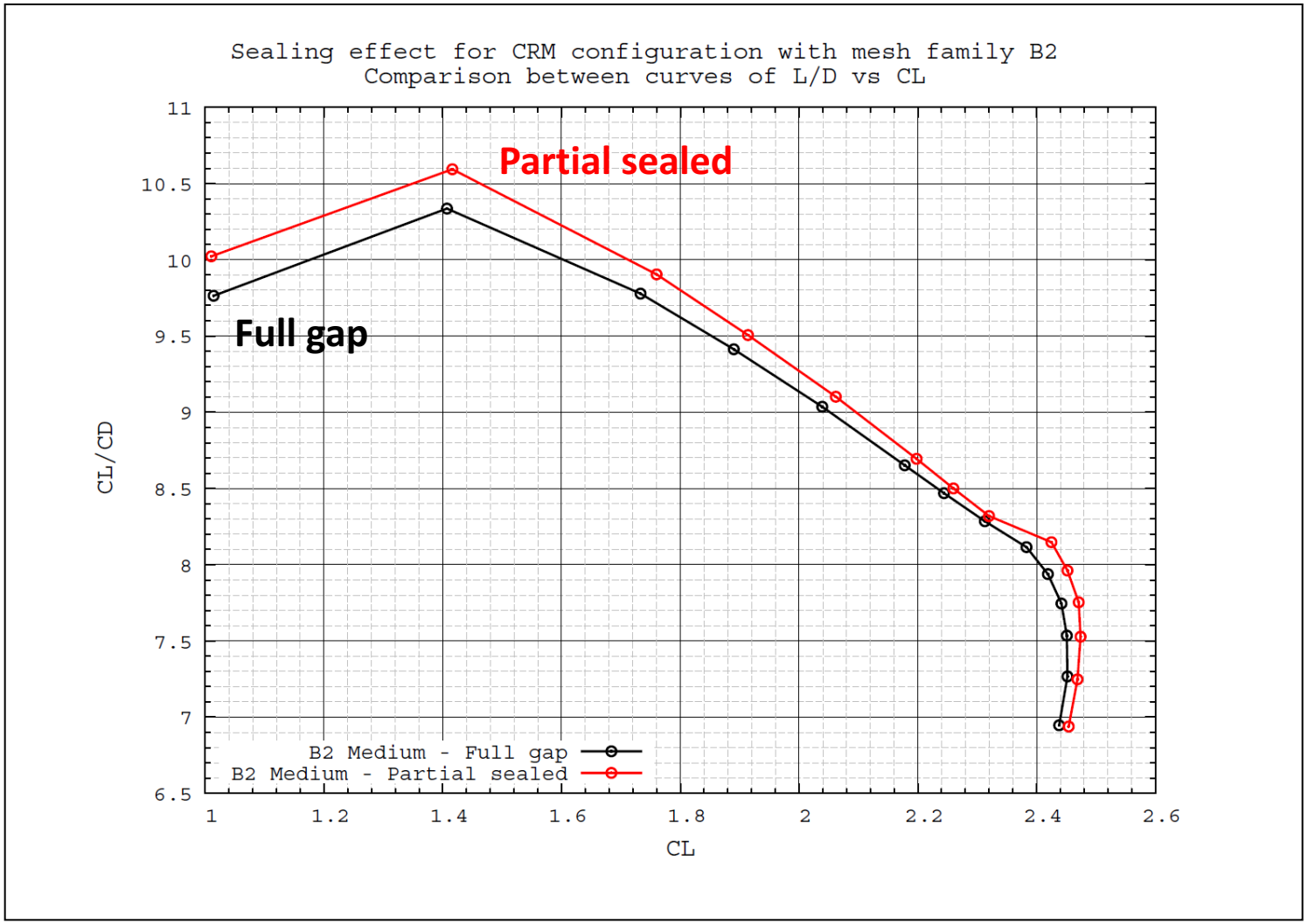
HL-CRM results – sealed gap x non-sealed

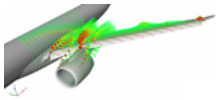


HL-CRM results – sealed gap x non-sealed



HL-CRM results – sealed gap x non-sealed



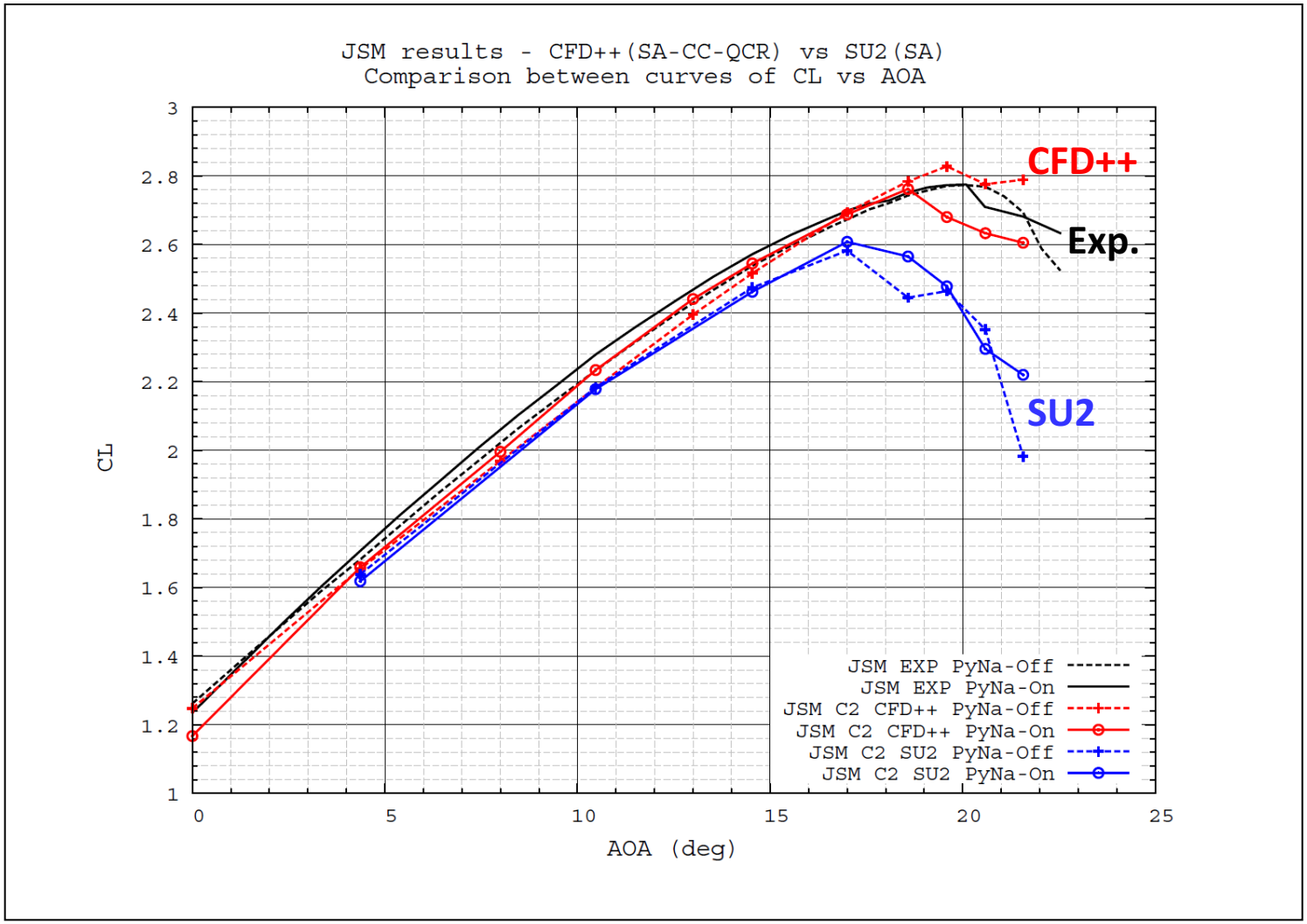


JSM – APPENDIX

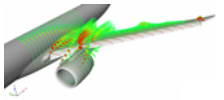
JSM results – CFD++ x SU2

SU2: SA

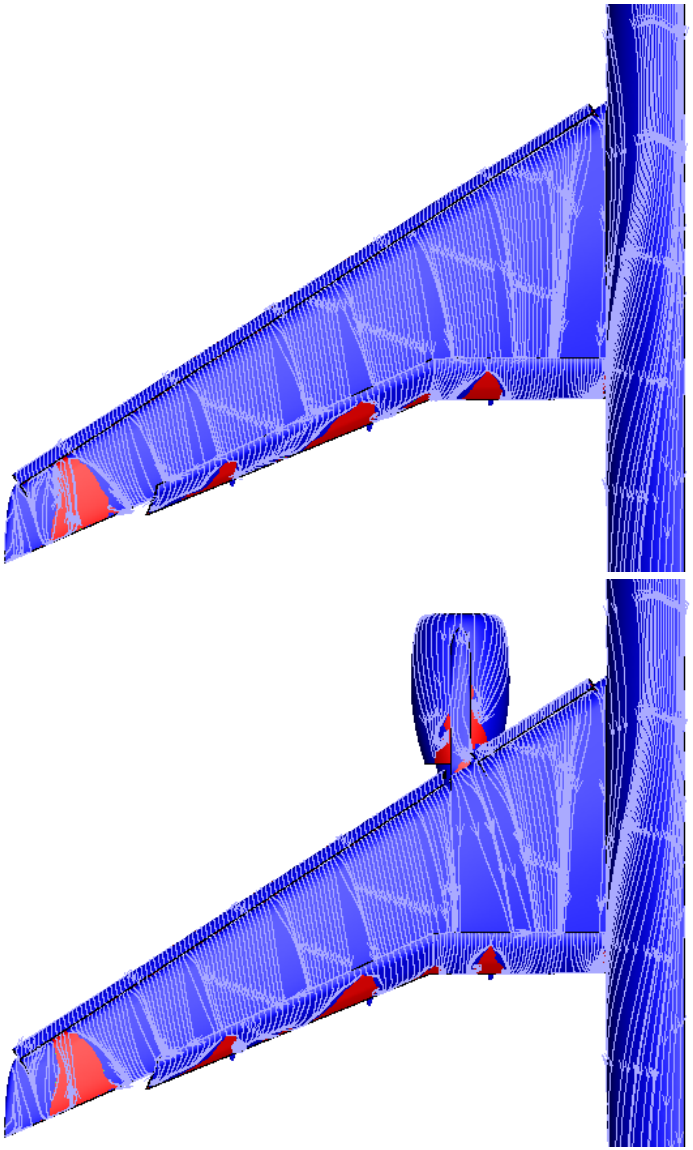
CFD++: SA-CC-QCR



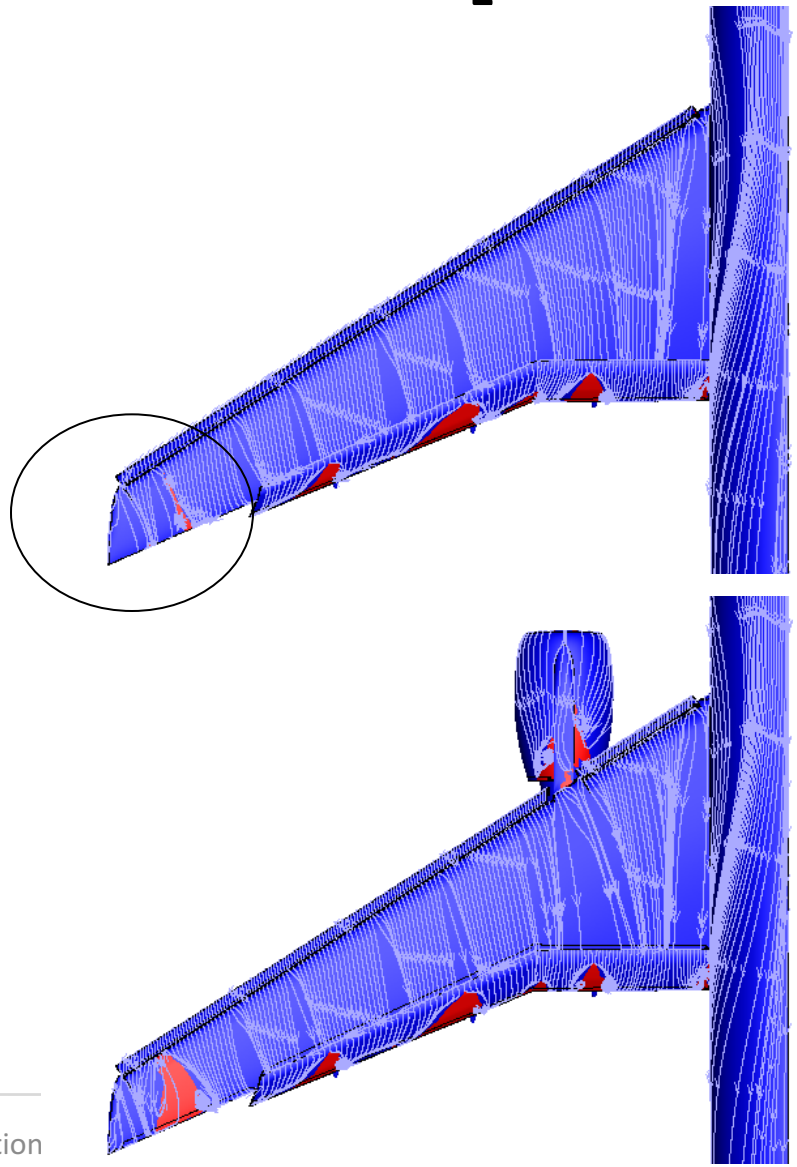
JSM results – PyNaOn x PyNaOff – 8°



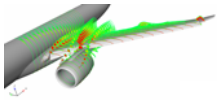
C2



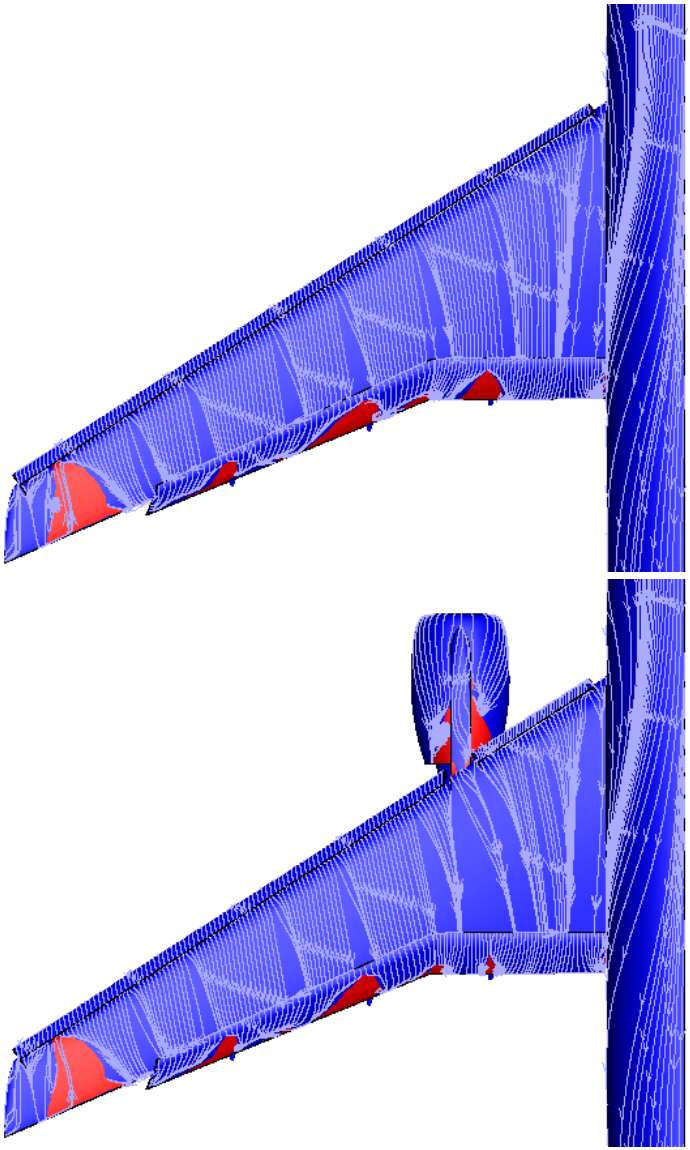
E



JSM results – PyNaOn x PyNaOff – 10°



C2



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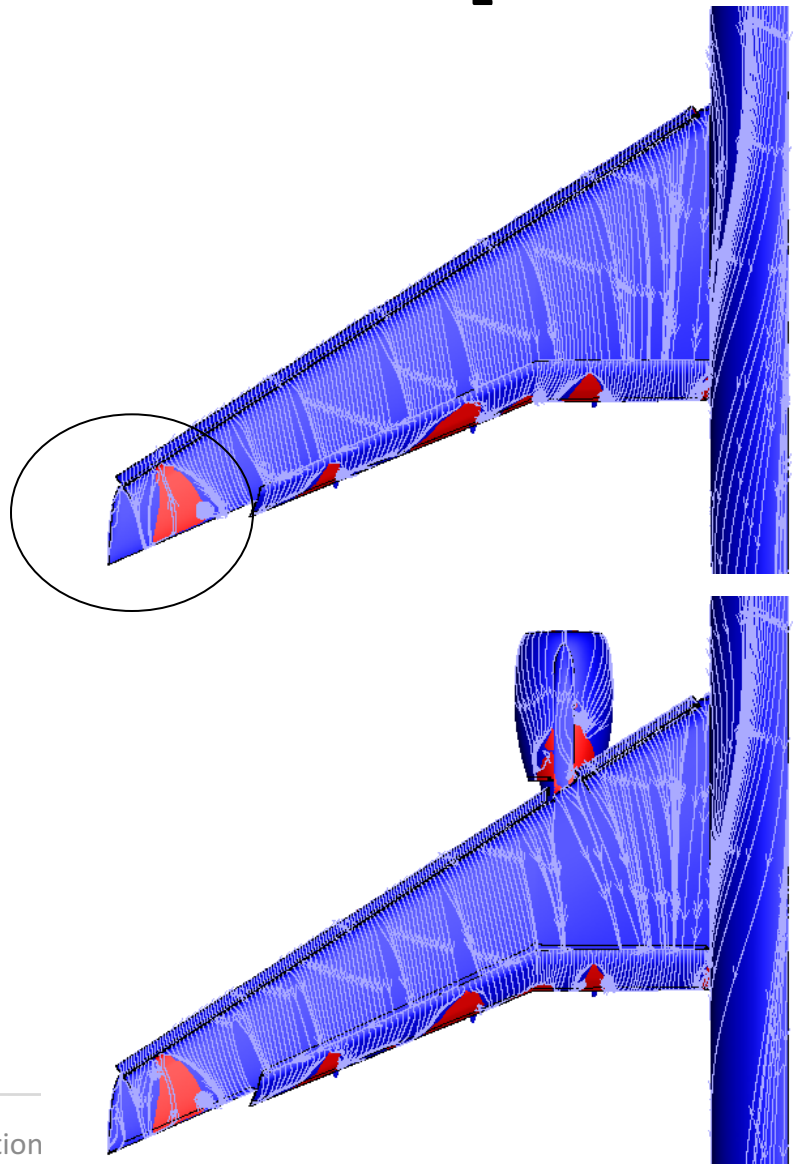
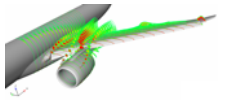
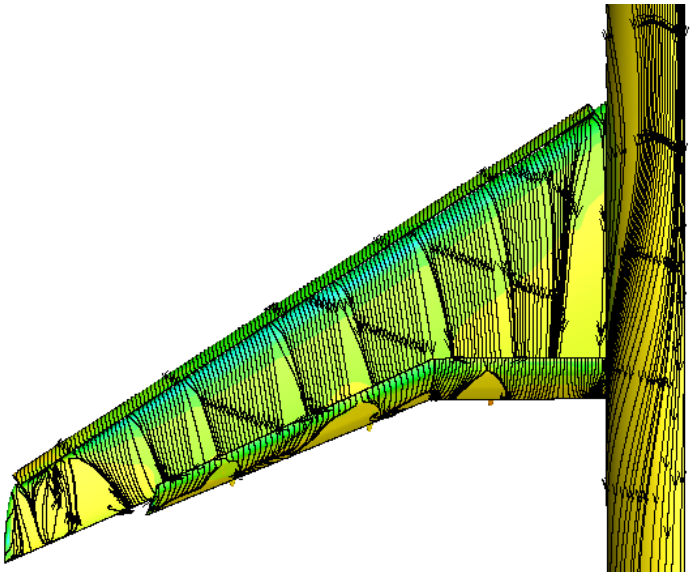
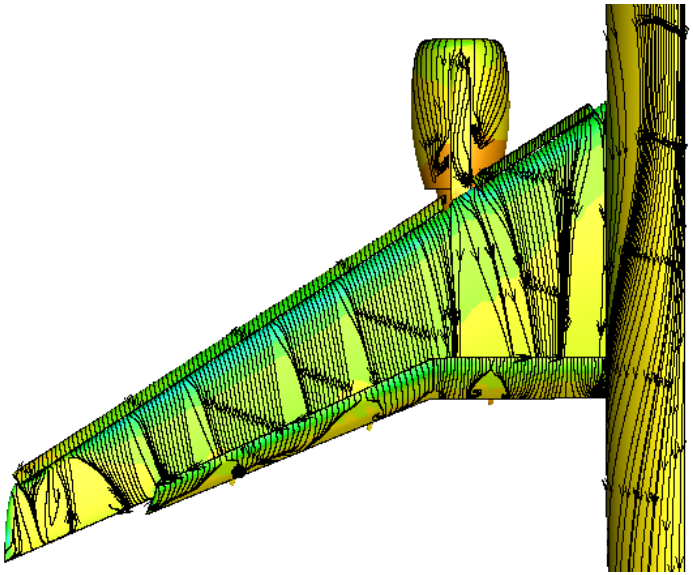


JSM results – PyNaOn x PyNaOff – 8°

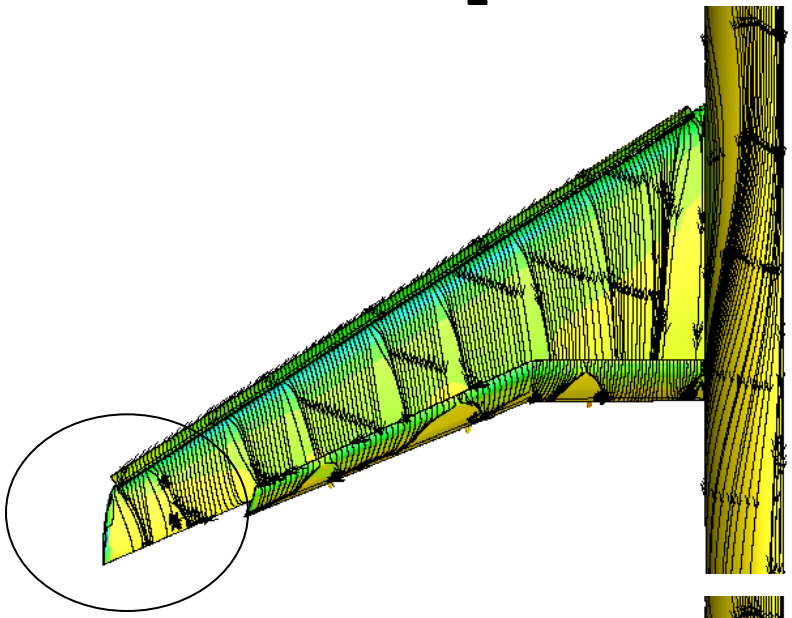


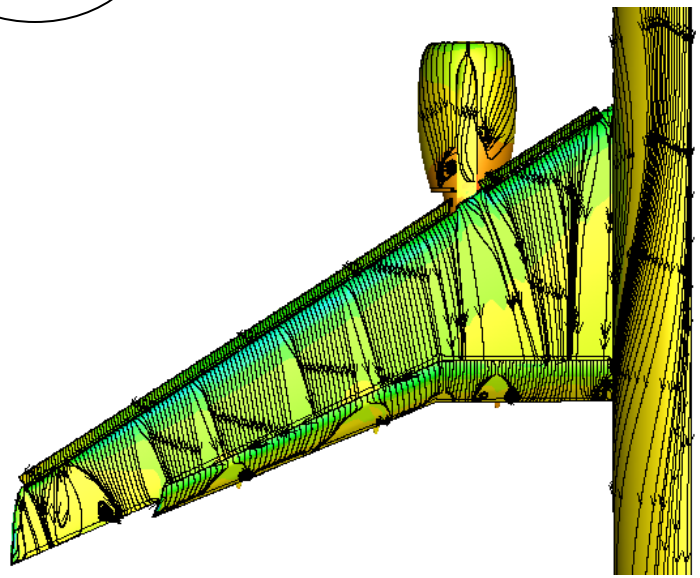
C2



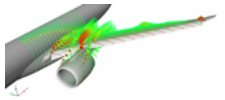


E

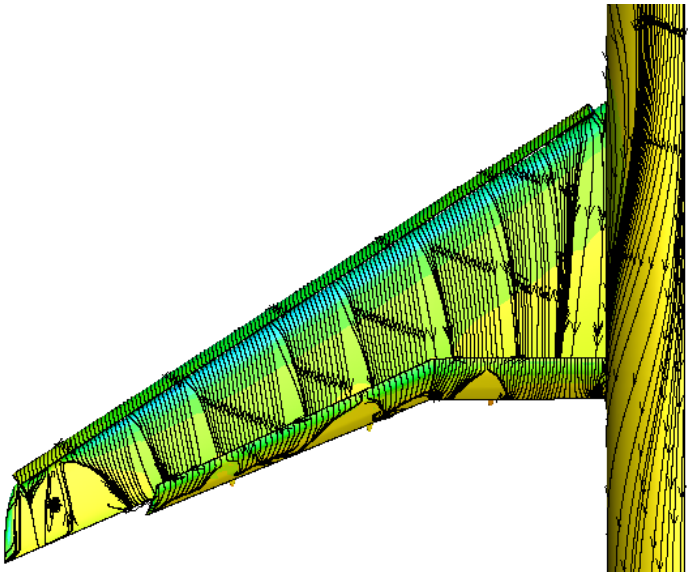


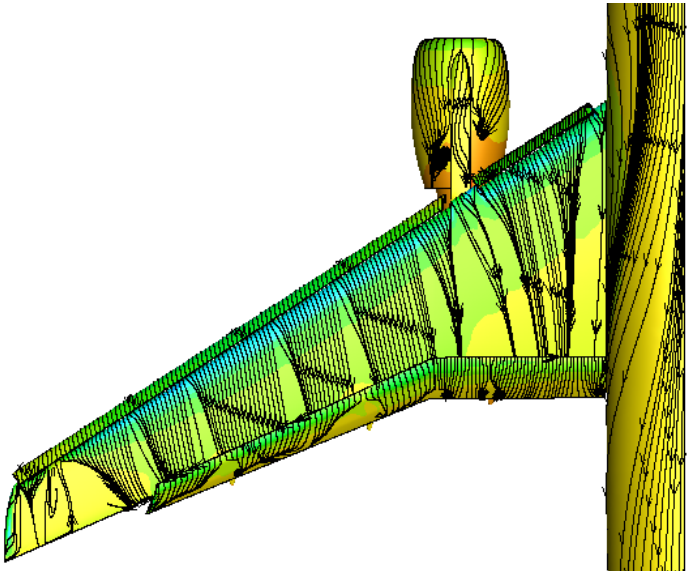


JSM results – PyNaOn x PyNaOff – 10°



C2





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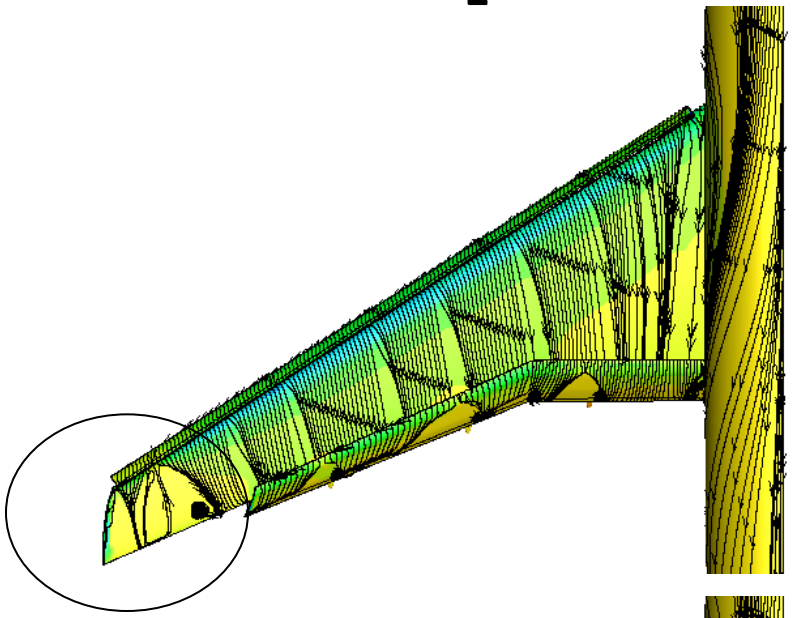
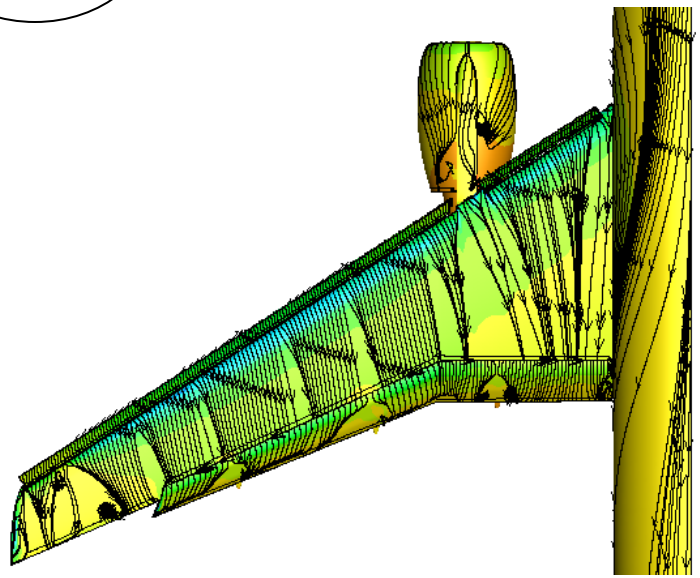
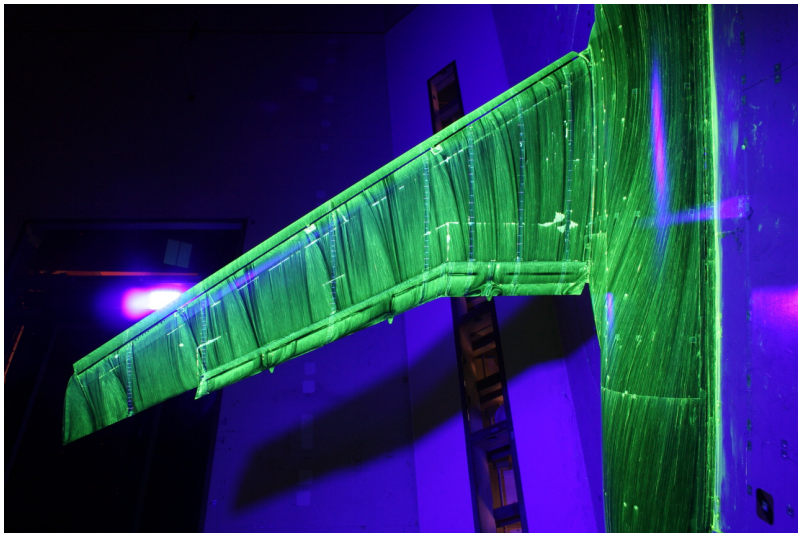
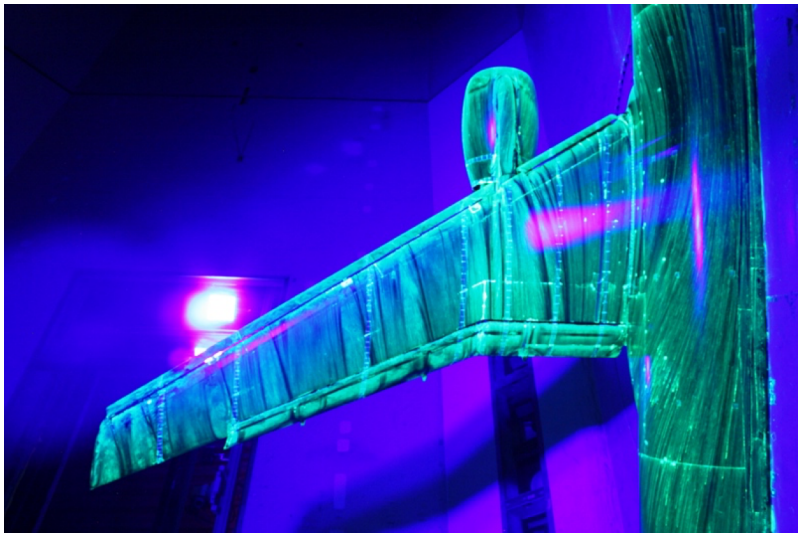
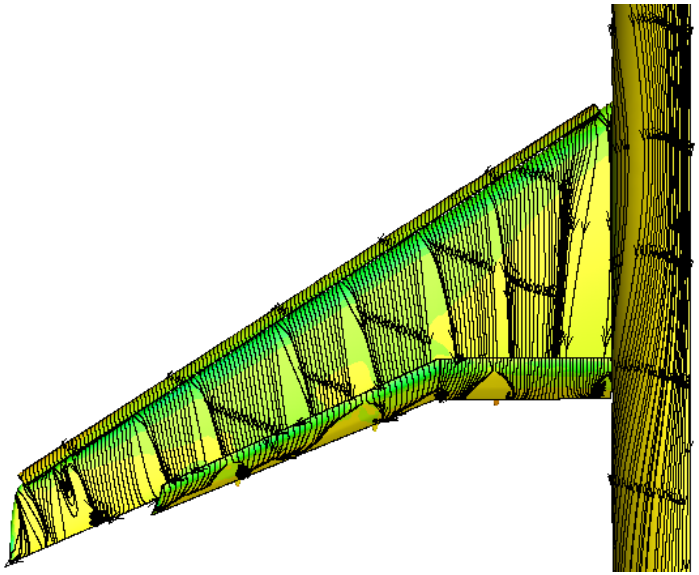


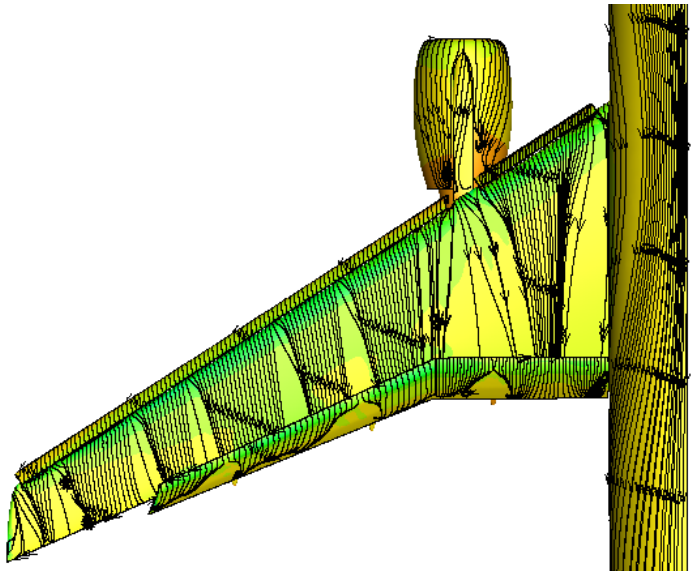


JSM results – C2 – PyNaOn x PyNaOff – 4°

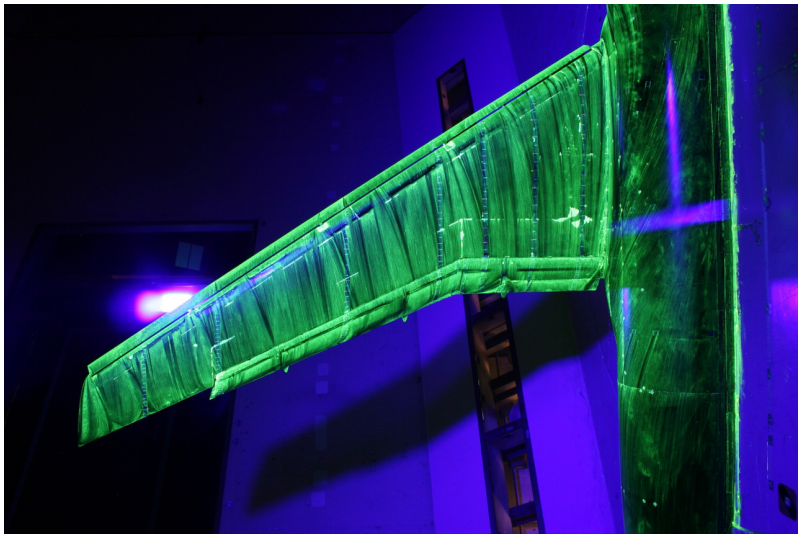


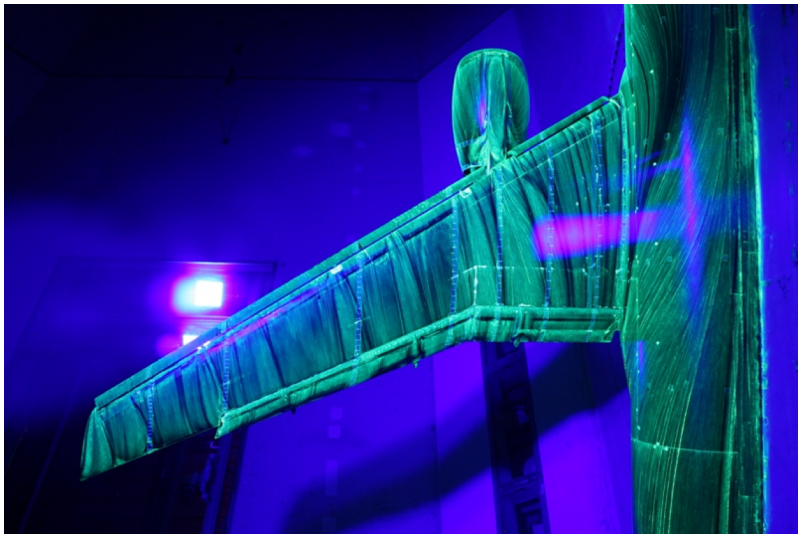


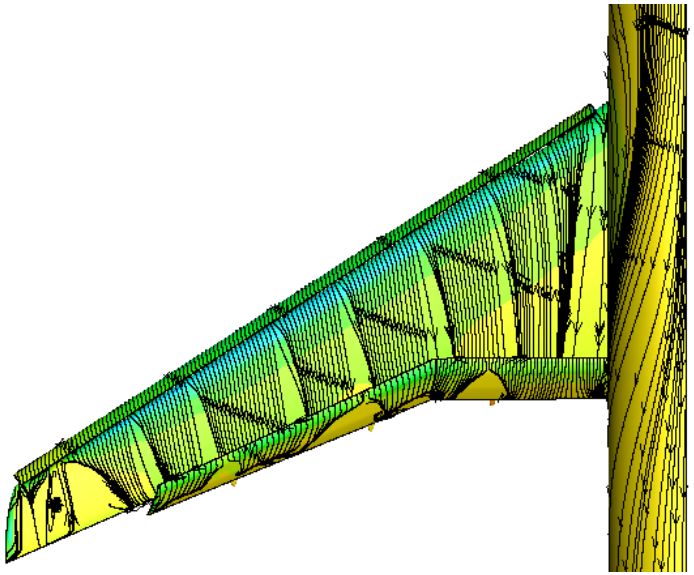


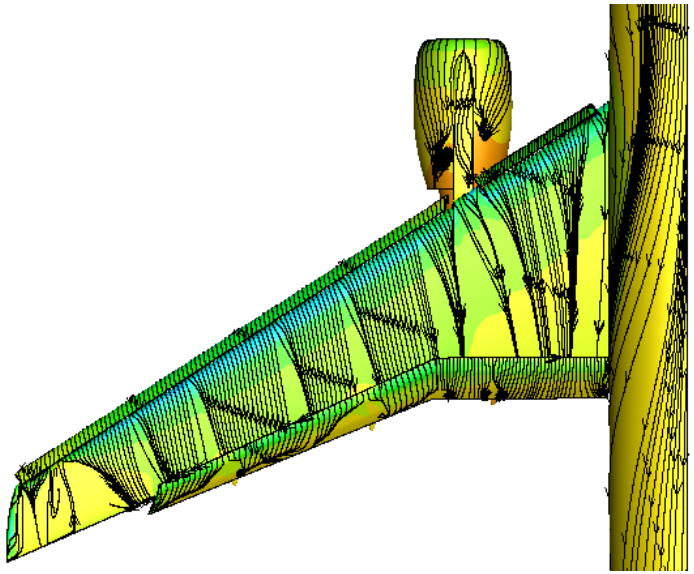


JSM results – C2 – PyNaOn x PyNaOff – 10°

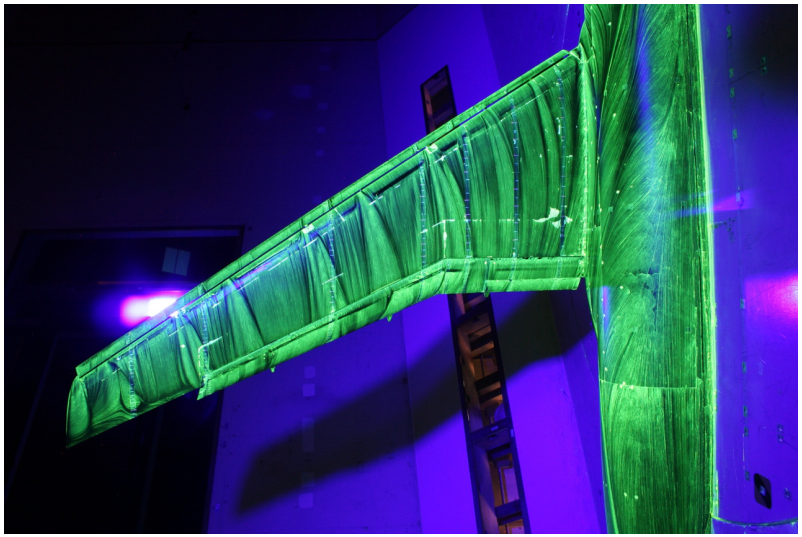


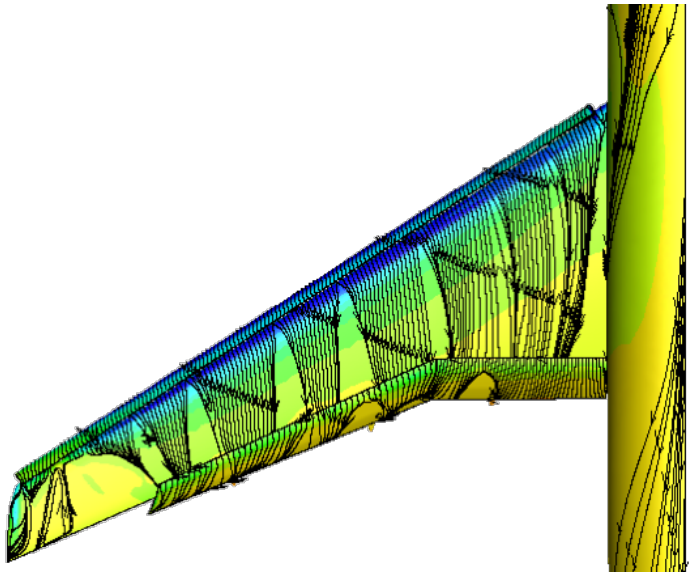


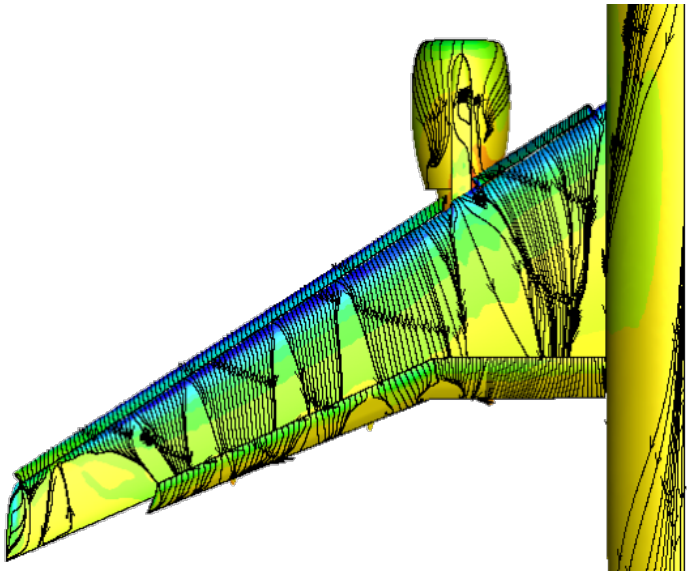




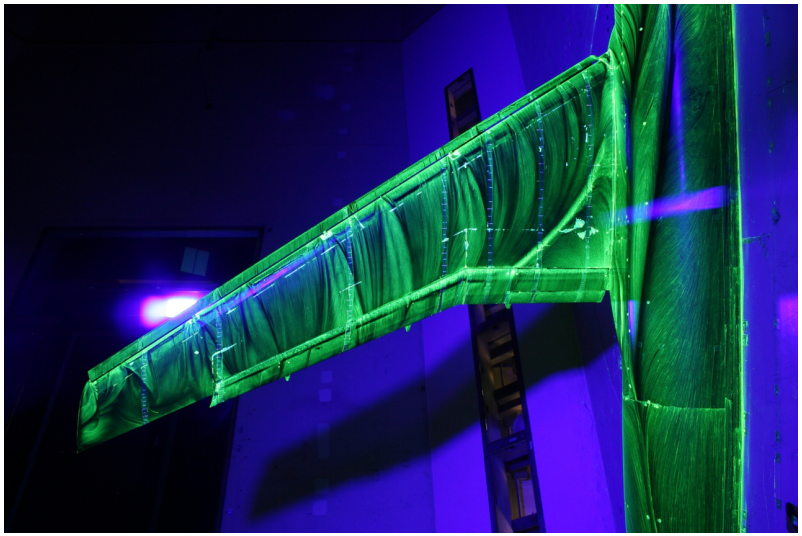
JSM results – C2 – PyNaOn x PyNaOff – 18°

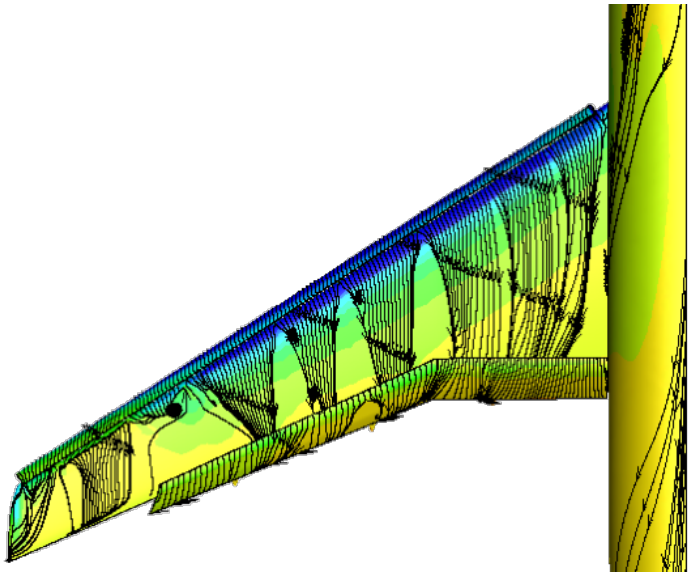


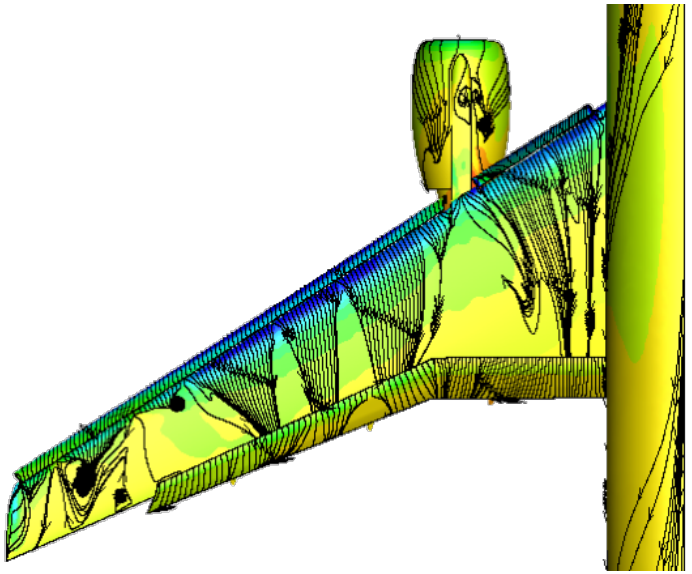


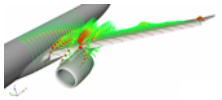


JSM results – C2 – PyNaOn x PyNaOff – 21°



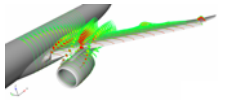






Case 3 – APPENDIX

Turbulence model verification study results



- Observed differences in coefficients between
  - SA
  - SA-CC-QCR
- Small differences in CL and CDviscous
  - 0.0015 in CL
  - 0.0003 in CD